An Integrated Computerised Maintenance Management System (I-CMMS) for IBS building maintenance

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Abstract

Purpose – The purpose of this paper is to focus on the development of an integrated computerised maintenance management system to improve the information storage of design and construction, diagnostic and defect risk assessments on IBS building through the integration of building information modelling (BIM).

Design/methodology/approach – The methodology used interviews with the IBS building client/maintenance contractor in Malaysia to gather information about maintenance management problems, approaches to address problems, information and communication technology implementation and use of emerging technologies, in addition to prototyping a system development life cycle for system development.

Findings – Relevant process flowchart documents of system development were obtained from the case study and reviewed to assist in providing an automation technique for decision-making and structural defect diagnostic operation through the integration of Visual Basic.Net, MS Access and Autodesk Revit software.

Originality/value – This research focuses on automatic bidirectional communications between an Expert System and BIM on a database level. Adoption of the approaches suggested in the research will enable the system to promote the development of zero IBS building maintenance.

Keywords Decision making, Maintenance management, Database, Automatic bidirectional communications, BIM technology, IBS buildings

Paper type Technical paper

1. Introduction

Building maintenance is facing poor management in Industrialised Building System (IBS) construction projects. According to Kamar et al. (2009) and Mohamad et al. (2016), IBS component aesthetic and structural defects that occurred repeatedly such as building maintenance on conventional building, no integration between maintenance systems, lack of coordination between design and construction, less defect diagnosis in decision-making process and lack of the intelligent capabilities of linking defect diagnosis operations in maintenance affecting various building elements with IBS component defects knowledge have led to significant problems in the IBS building maintenance management. The absence of standard diagnosis tools and guidelines for the prefabricated components contributes to an additional cost to redesign the project when measuring the maintenance delivery in IBS construction; thus, it leads to the increase in maintenance and operation cost, including construction time, production and labour cost (Chang and Tsai, 2013; Chen et al., 2016; Salama, 2017; Jabar et al., 2018). The limited systematic decision-making process due to a lack of integration between team members when dealing with risk management in the IBS construction projects is also problematic in maintenance management. There is no best method for problem solving and decision making under these circumstances (such as difficulties of maintenance planning and insufficient knowledge about building materials and component maintenance requirements) (Hamid et al., 2011; Zakaria et al., 2012; Wood, 2012; Chiu and Lin, 2014; Hadi et al., 2017).
Most of the maintenance management processes up till now use conventional methods with little emphasis on decision-making and defect diagnosis tools. The conventional methods mean that all the design and construction processes will be conducted in a sequential manner to provide maintenance teams in assessing building degradation, choice of optimal maintenance strategies for component or materials in an IBS building with the most minimal life-cycle analysis of projects (e.g. requirements, operational, and maintenance information) (Ismail, 2014; Naw, Lee, Azam and Kamar, 2014). Modern developments in information and communication technology (ICT) related to the construction industry are now commonplace for facilitating maintenance on various activities (failure analysis, documentation of maintenance, fault location, repair and reconstruction). An example 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 the process capability in the information and knowledge for dynamic decision making (Ruiz et al., 2013; Zhang et al., 2017). A few researchers have considered IBS to provide more efficient decision support tools in diagnosis such as Prefabrication, Preassembly, Modularisation and Offsite Fabrication, Interactive Method for Measuring PRE-assembly and Standardisation, Prefabrication Strategy Selection Method, and Construction Method Selection Model. Nevertheless, these existing tools consider inadequate aspects of sustainability (Yunus and Yang, 2012; Salama, 2017). Sustainability involves issues such as the design and management of buildings; materials performance; operation and maintenance; long-term monitoring; and the dissemination of knowledge in related technical contexts. Besides, most of the available system and assessment including diagnosis guidelines and tools are only used after the design of the IBS building project is about to be completed (Nawi, Salleh and Anuar, 2014; Mohammad et al., 2016). Due to the uncertainty and complexity of IBS building maintenance and diversity in the project environment, maintenance management is necessary to be efficient and effective at each stage of the life cycle of the building. Computerised maintenance management system (CMMS) applications to maintain a large number of buildings with quality methods can provide various reports pertaining to repair and maintenance issues that ensure better management of maintenance activities, as well as achieve a better quality in the transfer and evaluation of information among internal staff maintenance (Bucon and Tomczak, 2018). The computer-aided facilities management (CAFM) system to improve the usability of buildings can facilitate decision makers in the ability to automate a lot of intensive data for maintenance management functions that will generally result in cost savings on a regular basis (Roka-Madarasz et al., 2016).

At present, building information modelling (BIM) is most often dominating as a new system in maintenance management processes for high-rise and complex IBS buildings that enable effective maintenance and maintenance data. BIM has the potential to help improve the quality of maintenance management by visualising a large amount of data about building life cycle 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 to involving BIM as a building model digital in the maintenance phase where it has detailed building specifications in a system that facilitates computer-based maintenance management controls (e.g. geometric information, functions, features or parameters), allowing identification of errors immediate build and collaboration among various professionals in design to produce improved coordination, reducing time and building defects (Ghaffarian-Hoseini et al., 2017). Many studies have suggested for BIM solution integration for various projects throughout the life cycle of the building, including maintenance management. According to Carbonari et al. (2016), the concept design in the BIM system is ideal for high-rise and complex IBS buildings to support consistent visualisation and design, cost estimation, evaluation, monitoring, retrofit planning, lean maintenance and enhancing collaboration between maintenance teams. Kensek (2015) and
Roberts et al. (2018) investigate the possibility of detecting any potential defects and defects potential 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 actual situation of the building in the construction project and to gather information such as defect diagnosis and prevention for IBS building maintenance.

This paper presents a development for the application of integrated computerised maintenance management system (I-CMMS) in managing maintenance for complex and high-rise IBS building. By having this proposed prototype system through the management structure and implementation process, the defect diagnosis and decision-making process become easier, faster and cost effective in facilitating the maintenance assessment, defect diagnosis and control in relation to an IBS building structure component.

2. Characteristics of IBS building maintenance management

The selection of assessment or diagnosis tools on IBS construction sites has a significant effect on the lifetime performance of building structures, owing to the lack of real-time referential materials. In this situation, the absence of available diagnosis tools and guidelines of cooperation among construction parties create an additional cost to redesign the project when measuring the maintenance delivery in IBS construction (Chen et al., 2016). The repairing maintenance method (conventional system practices) restricts contractors and manufacturers from being involved in the design stage of a performance project, which often results in design changes and increase in the corresponding maintenance and operation cost, including construction time, production and labour cost (Chang and Tsai, 2013; Salama, 2017). The conventional system is basically less co-ordinated between the design and construction phase as it is conducted in a sequential manner (Mohamad et al., 2016). The conventional system approach in maintenance management has been criticised for various disadvantages such as repeating defects function and aesthetic due to inadequate technical knowledge, skilled manpower and low-quality control (Ogunde et al., 2018). Additionally, these repetition defects lead to high maintenance costs and thus lead to unacceptable quality in a project (Hadi et al., 2017). Most building maintenance personnel use conventional systems such as CMMS and CAFM to record information related to defects, diagnosis and maintenance planning. This information will then be converted into paper-based reports to be distributed to other staff involved in maintenance management. In addition, some maintenance organisations are using MS Word and MS Excel fully assisting maintenance works on specific functions (Espindola et al., 2013; Zare et al., 2018). Nevertheless, there is no integration between the systems to enhance communication and collaboration between all parties in maintenance management, particularly that involve the transfer of knowledge in the process of diagnosis of defects in buildings (Miettinen and Paavola, 2014; Nawi, Lee, Azman and Kamar, 2014; Carbonari et al., 2016).

The PC maintenance management application also has less intelligent capability to link the assessment of defects in maintenance that involves various building elements with the knowledge of defects in PC components (Talebi, 2014; Kim et al., 2015). This presents a problem in the transfer of information especially in obtaining information on the design specifications, the properties/type of the construction material and the previous maintenance management records causing the consultant/contractor/client to have no knowledge in solving the relevant defects problem regarding the diagnosis for the recovery of the defect. In addition, most processes in the CMMS system and CMMS integration with existing PC BIM systems also focus only on the process of defect identification and not on more critical maintenance management processes such as defect assessment processes, planning and execution in decision-making diagnosis. New developments in the process of assessing and improving the CMMS at the identification level through the enhancement of
the functionality and capabilities of the BIM system can change the way the application works. BIM can store information and update the maintenance records that have been performed and act as a smart system to diagnose defect and suggest improvements that must be taken in the execution process. BIM also enables the maintenance information system to be integrated to assist the maintenance team to manage and share all information about defect planning of the PC defect components from time to time throughout the life cycle of the building (Nawi, Haron, Hamid, Kamar and Baharuddin, 2014; Roy et al., 2016).

Sophisticated system database management such as using a combination of overall assessment processes, planning and execution in decision making, and BIM is an important component of today’s integrated computing engineering systems. Because both combinations have not been fully integrated before in the field of PC repair, the requirement exists for the combination of maintenance management processes and BIM (Zhang et al., 2017). Hence, the main objective of this study is to develop an integrated CMMS that can integrate the entire process of managing maintenance to improve CMMS, integrate BIM applications in the assessment process and improve the planning and execution process of PC maintenance.

Figure 1 concludes the maintenance management problems based on the research for IBS building.

### 3. Advantage of IBS building maintenance management on BIM technology

According to Farr et al. (2014) and Chen and Luo (2014), the actual benefits of BIM along with its visual realisation capabilities are now comprehended and utilised for the best benefits of all stakeholders of a construction project, for example, BIM can be integrated into the project management and working process, which can also be used by most AEC sector for construction quality control and efficient information utilisation. Currently, in the IBS construction project worldwide, work has been carried out regarding the use of BIM in manufacturing, components tracking, waste reduction, and supply-chain management (Cus-Babic et al., 2014). Building information models contain the information needed for particular phases of a building’s life cycle (scheduling, analyses, cost evaluation, etc.) and should offer construction new opportunities to improve the communication and collaboration between participants through higher interoperability of data.

**Figure 1. Key problems for IBS building maintenance management practices**
Kota et al. (2014) and Carbonari et al. (2016) state that the BIM systems can also provide the industry with the potential to improve construction life-cycle assessment, sustainability, structural analysis, daylight simulation, enhancing monitoring and project performance measurements (through sensors). The use of BIM system in the IBS building construction industry is to monitor post-construction stage for maintenance management through the life-cycle data that are created by BIM (e.g. requirements, operational and maintenance information) (Motawa and Almarshad, 2013). The examples of BIM applications stated by researchers in maintenance management are as follows:

- **Condition assessment/identification**: BIM systems can enable a 3D visual approach for the visualisation of components conditions through the life-cycle data during the construction and operation phases. The visualisation criteria can be automatically identified by two primary characteristics: the status and colour coding to infer the spatial patterns for certain problems and the history of changes in the properties of components to infer the changing patterns and the cause–effect relationships between different components over time using BIM. For example, visualising the changes in the condition of components over time can be used to identify the periods during which a component deteriorated, updating and immediately responded, electronically as well as faster than the manual average value or has an abnormal change in its condition (Motamedi et al., 2014).

- **Defect management**: a BIM-enabled process can automatically detect dimension errors and omissions more efficiently than the current manual-based defect management process, reduce site manager’s workloads, reduce rework-related costs, prevent reinforcement concrete work defects proactively with reliable advance information, and can save time by allowing quality inspection without visiting the real work site (Kwon et al., 2014).

- **Accurate drawing status on building delivery**: provide accurate information about a structural building information model to produce details (shop drawings), potentially saving project time and avoiding liquidated damages, which can then be used to guide effective building structure fabrication and eventual installation. This situation can easily be supported by using a 3D visualisation, for example, to provide interactive 3D views to the rebar installers, particularly on complicated and tight assemblies of concrete reinforcing (Clevenger and Khan, 2014).

### 4. Methodology

The case studies on the eight PC buildings were undertaken in order to identify the maintenance management problems, the current approaches to addressing the problems, the ICT implementation, use of emerging technologies and the maintenance management system (MMS) to obtain information relating to the maintenance identification, assessment, planning and execution processes. Eight maintenance clients/contractors are selected based on the major problems of using a conventional method (paper-based reports/unsystematic database) in order to investigate the maintenance management practices in each PC building. There are around 51 active contractors of IBS building maintenance from a classification of PC system in Malaysia according to CIDB and almost are using a conventional method and inadequately use of modern ICT tools (Nawi, Salleh and Anuar, 2014). The number is considered very big indicating that the use of modern ICT is still very limited for the PC system classification in IBS building maintenance management in Malaysia. The recommended sample size for interviews to obtain satisfactory results in phenomenology should be between 6 (Morse, 1994) and 25 (Polkinghorne, 1989; cited in Cresswell, 2007) individuals “who have all experienced the
phenomenon” (Cresswell, 2007, p. 61); hence, 8 key professionals working in IBS building maintenance units were interviewed in this study.

The interviews with the engineers consisted of two types of PC building, namely, “residential” and “non-residential”. The case study was based on eight cases (Cases A–H) of PC buildings in Malaysia. There were two case studies (Cases A and E) on “residential” due to housing maintenance operation such as the Putrajaya Quarters. In addition, six more case studies (Cases B, C, D, F, G and H) were classified as “non-residential”, which manage the maintenance operation with fully equipped office buildings. The interview sessions took around five hours to accumulate the data on the maintenance processes including the demonstration of the current MMS with the implementation of the ICT tools by the engineer and reached a saturated point after the eighth interview session. The justifications for the selected case studies were according to the following main criteria: exposed to the conventional method used and major problems, attempted to implement computerised technology and the willingness of staff to share their experiences in improving the maintenance management processes at the PC building. The differences between the types of the PC building project provided an opportunity to explore variations in maintenance management issues for complex and high-rise PC building projects. Based on the standard Life Safety Code, known as NFPA 101, the design of high-rise buildings is a building that has a height of more than 79 feet (24 m) or with an altitude of up to six floors. Meanwhile, the specification for the design of the PC complex building refers to the combination of several different buildings within a project site (Cote, 2012). The types of PC buildings surveyed for maintenance projects are entirely different from the Quarters to the Integration News Centre building. Professional maintenance staff members were interviewed – engineers who had experience with maintenance management practices. A summary of the case studies and eight respondents is presented in Table I.

The adopted synthesis of good practices of maintenance operations in I-CMMS is based on the findings of the interviews and case studies conducted with eight professional engineers working in IBS building maintenance departments for complex and high-rise IBS building (Ismail et al., 2016). This paper is part of a larger research and will only introduce and discuss the prototype of the system. This prototype is illustrated in the following sections.

In this research, the new MMS of I-CMMS was intended to improve the maintenance management problems at the IBS building, which are:

1. defect repetition due to failure to identify the actual reason of structural defect;
2. defect repetition (leaking, jointing and cracking) due to design defect; and
3. less competent contractor due to the lack of knowledge regarding materials, method and design of structural repair.

5. IBS building MMS with BIM technology

In the IBS building maintenance, the conventional methods to the project delivery and its failure to form effective communication channel between complementary knowledge on IBS construction and related members that is conducted in the sequential manner has resulted in ineffectiveness for managing building maintenance, where a paradigm shift within the IBS traditional approach is necessary (Girmscheid and Rinas, 2012; Wood, 2012). Therefore, the need for sophisticated tools and efficient techniques using an appropriate ICT (e.g. BIM and CMMS) for implementing an integrated approach in the design and construction could facilitate new maintenance management processes for IBS building projects in the future (Nawi, Lee, Azman and Kamar, 2014; Hosseini et al., 2018). In the meanwhile, most of the maintenance industries have been generally revolved around a conventional method.
<table>
<thead>
<tr>
<th>Interviewee</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>G</th>
<th>H</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type of IBS building project</td>
<td>Quarters</td>
<td>Malaysian Institute of Pharmaceuticals and Nutraceuticals (IPHARM)</td>
<td>National Youth Skills Institute (IKBN)</td>
<td>Anti-Corruption Agency Office Complex and Housing</td>
<td>Double Storey Super link House</td>
<td>Inland Revenue Board of Malaysia Complex</td>
<td>National Audit Department Office</td>
<td>Integration News Centre</td>
</tr>
<tr>
<td>Type of building</td>
<td>Residential</td>
<td>Non-residential</td>
<td>Non-residential Complex</td>
<td>Non-residential</td>
<td>Residential</td>
<td>Non-residential</td>
<td>Non-residential</td>
<td>Non-residential</td>
</tr>
<tr>
<td>Design of IBS building</td>
<td>High-rise</td>
<td>High-rise</td>
<td>Complex</td>
<td>Complex</td>
<td>High-rise</td>
<td>Complex</td>
<td>High-rise</td>
<td>High-rise</td>
</tr>
<tr>
<td>Cost of IBS building</td>
<td>1.1bn</td>
<td>124m</td>
<td>90m</td>
<td>23.4m</td>
<td>13.6m</td>
<td>45.4m</td>
<td>12.3m</td>
<td>100m</td>
</tr>
<tr>
<td>IBS component used</td>
<td>Precast concrete, blockwork system, formwork system</td>
<td>Blockwork system, formwork system, steel framing system</td>
<td>Precast concrete system</td>
<td>Precast concrete system</td>
<td>Precast concrete system, formwork system, steel framing system</td>
<td>Blockwork system, formwork system, steel framing system</td>
<td>Precast concrete system, formwork system</td>
<td>Precast concrete, blockwork system, formwork system</td>
</tr>
<tr>
<td>Person interviewed</td>
<td>Engineer</td>
<td>Engineer</td>
<td>Engineer</td>
<td>Engineer</td>
<td>Engineer</td>
<td>Engineer</td>
<td>Engineer</td>
<td>Engineer</td>
</tr>
<tr>
<td>Years of experience</td>
<td>10 years</td>
<td>20 years</td>
<td>10 years</td>
<td>4–5 years</td>
<td>24 years</td>
<td>21 years</td>
<td>4–5 years</td>
<td>10 years</td>
</tr>
</tbody>
</table>
(e.g. MS Word and MS Excel) with limited uses of 3D models for visualisation and maintenance development (Singh et al., 2011). Recently on IBS construction sites, a lot of efforts have been put in to improve the efficiency of maintenance management activities through the use of more ICT-based systems (i.e. BIM). With the development of emerging technology such as BIM, maintenance management improvements in IBS building construction have become possible (Nawari, 2012). Several other industry projects worldwide, for example, real estate, waste management, transportation, supply chain and facility management, have been successfully completed by implementing BIM technology (Cheng and Ma, 2013; Mahdjoubi et al., 2013; Irizarry et al., 2013; Marzouk and Abdelaty, 2014; Love et al., 2014). BIM can assist clients to determine the appropriate technology strategy and scope of each deliverable, with the intention of reducing redundancy and rework while improving performance and productivity of an operation and maintenance processes effectively in the future (Love et al., 2013; Miettinen and Paavola, 2014; Carbonari et al., 2016). Whereas BIM-related studies mainly focus on utilising a sophisticated tool and efficient technique, associating decision-making support with diagnosis principles can help in achieving new levels of efficiency in IBS building maintenance performance. The defect diagnosis in maintenance management becomes a challenge for storing and processing quality maintenance data of precast concrete elements to provide the reliable inspection due to ineffective implementation strategies, and best practices need to be undertaken with the implementation of BIM-based diagnostics system in the organisation (Kim et al., 2015). The effective management of maintenance diagnosis relies on the sophisticated technology, ensuring the success of dependable building facility and the achievement of the expected return on investment in maintenance (Jantunen et al., 2011). Another challenge for BIM technology is to provide the adequate strategic decision making to analyse diagnosis information and knowledge to improve the maintenance project outcomes (cost, time, quality, safety, functionality, maintainability, etc.) (Talebi, 2014).

The main objective of research focuses on the development of an appropriate system to improve information storage of design and construction, diagnostic and defect risk assessments on IBS building through the integration of BIM. This research focuses on automatic bidirectional communications between an Expert System and BIM on a database level. An Expert System is developed to automatically evaluate the defects and provide flexibility for different maintenance scenarios to gain better quality operation. BIM will be used during the construction phase and data collected from the Expert System will be integrated and updated in real time using Revit Application Programming Interface (Revit API) and Revit DB link for improving interoperability. The adoption of the approaches suggested in the research will enable the system to achieve the maintenance operation visualisation, information automation and multi-collaborative participation, which can effectively promote the development of zero IBS building maintenance.

Implementation of I-CMMS

The integration of modern ICT tools such as BIM, CMMS and Expert System facilitates the knowledge transfer for maintenance management processes in recommending the repair structure components needed for the efficacy of the maintenance management practices. From the case studies findings, the involved maintenance management processes are the maintenance identification (for defect report and assessment), defect and cause analysis (for defect diagnosis) and risk level analysis (for defect control) as the main stages in managing maintenance for IBS building structure and facility that are described in Figures 2 and 3.

6. Development of the MMS

The system architecture focuses on the collection of the structure and facility defect information for defect assessment, defect diagnosis and defect control as well as analysing
the data for the execution reference in IBS building maintenance. The mobile devices such as laptop enable staff to compare and adapt the data at any facility location with the staff’s report recorded in the prototype system user interface (MS Visual Basic.NET). The staff will be able to capture the evidence of the structure and facility defect, update about

![Diagram of Maintenance Management System]

**Figure 2.** The configuration of maintenance management system improvements

**Figure 3.** Maintenance management processes
the detailing defect and record the relevant aspect of the defect attribution in an electronic form in the prototype system. This information is stored in a computer database central (MS Access) at the office for further process. The information about the defect is assessed using the maintenance condition index for considering the current condition of the structure and its components, analysed for the maintenance defect diagnosis using the decision-making process and assessed using the design condition index for reducing the risk of design defects at the site location. The workflow is illustrated in Figure 4. I-CMMS can be divided into three main components, which are the BIM model, CMMS and Expert System. Each component plays a different role in the prototype system. The BIM model enables the analysis of design defect concrete component by comparing the defect and cause of the concrete against the 3D model including the record model in the BIM database, whereas the CMMS provides the information of the defect report and assessment. The Expert System provides the concrete defect diagnosis function and selection of a durable replacement design and material, or the proper rehabilitation method for the system.

The framework was encapsulated in a computer-based prototype system based on Autodesk Revit to allow multidisciplinary information to be superimposed within one digital building model, Microsoft Visual Basic.Net as a graphical user-interface, whereas for the database design, the Microsoft Access was used to deploy the information for maintenance management processes. The computerised system was developed using a data flow diagram and coding. The defect report and assessment is the initial process where a technician will allege any defect component occurred in the building. The defect inspection is undertaken to measure the defect performance on site and then this information will be put in the system for recorded after the defect assessment value is determined. The database in the system is linked with the three softwares, namely, CMMS, Expert System and BIM model (Autodesk Revit). The knowledge transfer can be utilised through this system when
the knowledge of history for defect component from the defect report and assessment process is distributed to the engineer within the same organisation. The engineer is assigned to screen each of defect components for the diagnosis task in order to analyse the cause and reason of defect that ensued. The expert system can be used to examine the defect symptoms on each of the components that are based on the knowledge obtained from literature searches, codes of practice, manuals, textbooks, technical reports, journals and conference proceedings, civil work reports and experienced PC specialists. This diagnosis process consists of three knowledge bases, each of which contains information on the various types of defect in PC structures (e.g. shape, pattern, density and location). The required knowledge for diagnosing the PC defect is formulated as production rules (IF… THEN) and procedures and is incorporated in the knowledge base structure. These are typical forms of code in conventional programming languages. The knowledge base entry-type procedure uses syntax similar to the Visual Basic programming language within the body of the procedure. The diagnostic trees served as the vehicle for communication between the experts who interpreted and organised the knowledge in a hierarchical structure and the knowledge engineer who initially recorded the knowledge into a question-and-answer sequence form along with a network diagram. Information relating to several different methods for repair or rehabilitation of PC structures has been gathered and stored in the database. Selection of repair methods can be affected by the consideration of durability, constructability and compatibility with the existing structure and environment. The knowledge of defect diagnosis in the expert system is then transferred to the designer in the BIM model for pursuing the design defect cause and reason and even to classify the risk level of defect component. Finally, the knowledge of design defect based on the materials specification 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 will improve the defect diagnosis and decision-making process for critical defect element based on the maintenance impact undertaken heading to sophisticated management and maintenance effectiveness.

Figures 5–7 show how the expert system database collaborated with BIM technology through knowledge transfer to perform specialised tasks, which provides the report analysis of defect diagnosis for particular IBS building components in determining an Average Index Level (AIL). AIL numerically rates the condition risk of the design defect IBS concrete on a scale of 1–5 (Table II) by evaluating each concrete design deficiency based on the “Design Condition Index” form in Figure 7.

![Figure 5. Wall component is selected on a 3D floor plan](image)
Figure 6. Maintenance information based on the specific ID element is captured from the BIM database

Figure 7. Design condition index form from wall component selected is appeared afterwards

<table>
<thead>
<tr>
<th>Rating scale</th>
<th>Average Index (a)</th>
<th>Categories</th>
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<tbody>
<tr>
<td>1</td>
<td>1.00 ≤ a ≤ 1.50</td>
<td>Ignorable</td>
</tr>
<tr>
<td>2</td>
<td>1.50 ≤ a ≤ 2.50</td>
<td>Not important</td>
</tr>
<tr>
<td>3</td>
<td>2.50 ≤ a ≤ 3.50</td>
<td>Moderate</td>
</tr>
<tr>
<td>4</td>
<td>3.50 ≤ a ≤ 4.50</td>
<td>Important</td>
</tr>
<tr>
<td>5</td>
<td>4.50 ≤ a ≤ 5.00</td>
<td>Very important</td>
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Table II. The Average Index Level (AIL) for the evaluation of design defect

Each of the components in the 3D floor plan has a specific information for maintenance planning and execution produced by recorded data with the integration of expert system and CMMS. Therefore, when the particular IBS component is selected, the description screen of maintenance information is presented to elaborate the specific defects for consultant’s
reference. Then, the Design Condition Index Form is appearing to analyse the information with the calculation of AIL in order to justify the design defects evaluation. Table I intends to determine the condition level of design defects that either needs repair or not for a particular IBS component.

### 7. Prototype testing

The model was subsequently tested by eight engineers at complex and high-rise IBS buildings, and Table III shows the results from Sections 1 to 3 of the evaluation questionnaire. The table presents the numbers of respondents associated with each rating on the assessment scale (rating from 1 – strongly agree to 5 – strongly disagree) for each of the key aspects of the prototype. Based on the findings, most of the participants agreed with the effectiveness of all of them provided an answer for every question by “Strongly Agree” and “Agree”. In terms of the practicality of the prototype, it can be concluded that the developed prototype can be practiced in the IBS building maintenance management practices. Generally, the overall participants agreed for the prototype usability where the maintenance professionals who have work experience with the ICT environment are confident to use the prototype. The evaluation results show that the participants agreed that

<table>
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<th>Evaluation questions</th>
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<tr>
<td></td>
<td>5</td>
</tr>
<tr>
<td>1. Strongly agree No.</td>
<td>No.</td>
</tr>
<tr>
<td>2. Agree No.</td>
<td>No.</td>
</tr>
<tr>
<td>5. Strongly disagree No.</td>
<td>No.</td>
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</tbody>
</table>

**Section 1: prototype effectiveness**

1.1 Will increase team competence through more effective communication between the design team, construction and management of the facility

1.2 Will improve the control of defects through more effective design assessment on the components of the PC structure

1.3 Will facilitate the classification of answers in order to obtain sequences (sample categories, sections and sub-sections) from knowledge sources

**Section 2: prototype practicality**

2.1 I am comfortable with the idea of decision-making in the diagnosis of defects by incorporating new knowledge sources (through expert systems and BIM)

2.2 The information can be easily accessed from the location of the knowledge source for the type of disability database recorded

2.3 The system is practical in terms of access to knowledge resources using expert systems and Revit (BIM)

2.4 The system is very effective to enhance sharing and transfer of knowledge

**Section 3: prototype usability**

3.1 The prototype user-interface is simple enough for a maintenance team leader to learn and use for high daily tasks

3.2 Considerable training will be required for effective use of the prototype

<table>
<thead>
<tr>
<th>Evaluation questions</th>
<th>Rating</th>
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<tbody>
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<td></td>
<td>1</td>
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<td>1. Strongly agree No.</td>
<td>No.</td>
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<td>2. Agree No.</td>
<td>No.</td>
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<td>5. Strongly disagree No.</td>
<td>No.</td>
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</table>

**Table III.**

The responses to evaluation questions
the prototype offered a useful and systematic approach to solving maintenance management on IBS building maintenance projects. It shows that the prototype could facilitate the tackling of IBS building maintenance problems.

Validation results on the prototype system are with a score of 1 or 2 rating, confirming a system that is most appropriate for the purpose of diagnosis of defects and design defect assessment and even has reliability for other purposes, i.e., for root response generation and defect repair method against the PC. Evaluation of key requirements or specifications in the process structure has also shown that the prototype system can improve the quality of automatic bidirectional communication in the process that is not available in conventional systems.

**Limitations of the prototype system**
The evaluation sessions also investigated the comments regarding the limitations of the prototype system. There were a few limitations of the prototype system highlighted by the participants during the discussion:

- There were also constraints on engineers with limited computer literacy. Other restrictions such as size and cost of the project, ease of use and participation from contractors also resulted in the implementation of the prototype system.

- Other limitations mentioned included the cost and training needed for the adoption of the prototype system especially for BIM and Expert System element. There was also the appreciation of all engineers and the technicians with the implementation of the prototype system in the current practices of maintenance management processes.

**8. Conclusions**
The development of the prototype system in this research shows the improvement to the maintenance management processes by integrating maintenance management processes and information database. The following conclusions can be drawn from the research findings:

1. The prototype system is able to integrate BIM technology related to defect diagnosis data in order to provide better defect analysis for identifying and evaluating design risks for structural design components.

2. The integration of BIM database with expert systems and Design Condition Index can support design defect control efficiency in order to improve resilience and reduce maintenance requirements.

3. The result of concrete defect diagnosis in the expert system provides the user with recommendations related to the best course required for maintenance and in the selection of materials and methods for the repair of IBS components using the rule-based expert system in MS Visual Basic.NET.

**References**


An I-CMMS for IBS building maintenance


Further reading

Kroenke, D.M. (2012), Using MIS, Prentice Hall, IN, NJ.


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