BIM Technologies Applications in IBS Building Maintenance

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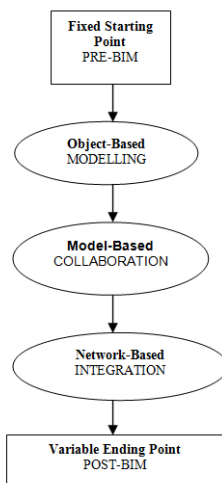
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Graphical abstract

Abstract

Because of their characteristic attributes of storing all the information of a building and visualising the maintenance process of a project over its entire lifecycle, generating the automated control and monitoring of building diagnosis (e.g. component utilisation, component failure, etc.) as well as providing decision support for the choice of maintenance measures and the scheduling of maintenance, BIM technologies have a special appeal for the building maintenance profession. In spite of this appeal, there are currently very few operational BIM technologies in the field of IBS building maintenance. One reason for this may be a lack of awareness by the industry as to what BIM technologies currently exist and what their capabilities are. Presenting this information to the potential users in an easily scannable format is one of the objectives of this paper. A second objective of this effort is to present the characteristics of the state-of-the-art BIM technologies to researchers and industry practitioners. This information will help them in making a choice of the most appropriate tools and trigger communication between users working in similar domains.

Keywords: Building Information Modelling (BIM) Technologies; Industrialised Building System (IBS) Building Maintenance; Malaysia

Abstrak

Oleh kerana ciri-ciri kualiti dalam menyimpan semua maklumat sesuatu bangunan dan menggambarkan proses penyelenggaraan projek di keseluruhan kitaran hayat perkhidmatan, menjana kawalan automatik dan pemantauan diagnosis bangunan (contohnya penggunaan komponen, kegagalan komponen, dan lain-lain) dan juga menyediakan sokongan keputusan untuk pemilihan langkah-langkah penyelenggaraan dan penjadualan penyelenggaraan, teknologi BIM mempunyai potensi besar dalam profesion penyelenggaraan bangunan. Walaupun dengan potensi ini, terdapat sangat kurang operasi teknologi BIM dalam bidang penyelenggaraan bangunan IBS. Salah satu sebabnya mungkin kekurangan kesedaran oleh industri tentang apa teknologi BIM termasuk keupayaan penyelesaiaannya. Menyampaikan maklumat ini kepada pengguna dalam format yang ringkas dan mudah adalah salah satu objektif jurnal ini. Matlamat kedua usaha ini adalah untuk membentangkan ciri-ciri 'state-of-the-art' teknologi BIM untuk penyelidik dan pengamal industri. Maklumat ini akan membantu mereka dalam membuat pilihan yang tepat tentang teknologi yang paling sesuai dalam meningkatkan komunikasi antara pengguna yang bekerja dalam bidang tugas yang sama.

Kata kunci: Teknologi Model Informasi Bangunan (BIM); Sistem Binaan Berindustri (IBS); Penyelenggaraan Bangunan; Malaysia

◼1.0 INTRODUCTION

Because of their characteristic attributes of storing all the information of a building and visualising the maintenance process of a project over its entire lifecycle, generating the automated control and monitoring of building diagnosis (e.g. component utilisation, component failure, etc.) as well as providing decision support for the choice of maintenance measures and the scheduling of maintenance, Building Information Modelling (BIM) technologies have a special appeal for the building maintenance profession. The following typical features of today's IBS building maintenance environment show the need for a BIM-like technology for improving Industrialised Building System (IBS) building maintenance quality and productivity.[1] According to Love *et al*., Miettinen & Paavola and Volk *et al*., inadequate technical knowledge and poor quality IBS products or components have led to significant needs in the BIM-based building maintenance management.[2,3,4]

- Lack of knowledge in structural analysis and design of pre-fabricated components;
- Improper detail design of ties and connections;
- Nonstandard joints complicating design by fixing reliance on a particular manufacturer;
- Communication issues among construction players;
- Difficulty of finding expert workers;
- Difficulty of training workers for assembly;
- Sequential assembly that makes future change difficult;
- Insufficient information about material and recovery methods;
- Inadequate information about material and component life expectancy;
- Insufficient information among builders about building systems;
- Insufficient coordination among design, manufacturing and construction components; and
- Deficient quality control.

In spite of the need and potential benefits, there are currently very few operational BIM systems in the field of IBS building maintenance. One reason for this may be a lack of awareness by the industry about what BIM systems currently exist and what their capabilities are. Presenting this information to the potential users in an easily scannable format is one of the objectives of this paper.

A second objective of this effort is to present the characteristics of the state-of-the-art BIM systems to researchers and industry practitioners. This information includes knowledge structure and system-building tools, which will help them in making a choice of the most appropriate tools, and trigger communication between users working in similar domains. The factor that will affect the use of BIM systems in the IBS construction industry is the nature of this industry, which is the absence of available diagnosis tools and guidelines of cooperation among construction parties when measuring the maintenance delivery in IBS construction.[5] The repairing maintenance method (fragmentation approach) restrict contractors and manufacturers from being involved in the design stage of a performance project, which often results in design changes and a corresponding maintenance and operation cost increase including construction time, production and labour cost.[6,7] According to Kamaruddin *et al*. and Rahman & Omar, the management level in Malaysia, monitoring, diagnosing technology and repairing maintenance method of IBS buildings is far behind some developed countries.[8,9] Compared with the relatively high level of IBS construction in the USA and Japan, the supporting technologies and large-scale production systems (such as supervision systems and matching construction technologies) are used to improve the construction maintainability of components and could diagnose the maintenance problems with safety monitoring process to prevent the building construction accidents.[10] Low defect diagnosis for building maintenance may cause great economic losses and personal casualty incidents due to the disaster building defect. For example, concrete roof of the Gong Badak stadium collapsed in Kuala Terengganu on June 2, 2009.[11] The roof structure crash occurred under construction for SMK Taman Connaught in Kuala Lumpur and three labours were injured on Jan 15, 2010.[12] In addition, a few of ceilings at a Hospital Serdang in Selangor collapsed for a third time as a result of its structural failure (steel corrosion) on November 14, 2013.[13] Thus, the management of maintenance in the complex and high-rise buildings claims a high emphasis on the systematic process for the improvement of maintenance management system of IBS construction.

The inefficiency in decision making process has been found to be a major cause of aesthetic and functional faults.[14] The defects include cracks, blemishes, moisture penetration, water leakage due to improper jointing and poor thermal insulation.[15] Many factors stimulate ineffective decision support to provide the sufficient information of maintenance strategy with the extensive coordination on technical knowledge requirements and schedules prior to maintenance operations of project implementation, however poor maintenance management or repairing maintenance method (fragmentation approach) deficiency can give a major impact to the IBS building maintenance activities.[14] According to Chen *et al*., the main reasons for not optimum decision making on IBS building construction projects were lack of knowledge and exposure to IBS technology, since the resolution implementation were based on familiarity and personal preferences (e.g. experience of the design team) rather than rigorous data between team members through regular meetings.[5] This is also supported by Bari *et al*., who agree with that the incorrect strategic decision at the initial project phase was a major cause of cost overrun and supply chain integration problem due to lack of comprehensive principles in the maintainability approach such as measuring convention, standardisation, buildability score and open system practices among IBS construction teams.[16] The integrated decision making process with the maintenance strategy from the design stage to the installation of components is needed that can significantly improve the repairing maintenance method of IBS building construction projects.[17] This could realise with a good management system with the implementation of BIM, to enhance managing efficiency for both defect diagnosis and decision making process, thereby establishing a more effective maintenance strategy for an IBS building construction.

◼2.0 STATE-OF-THE-ART BIM TECHNOLOGIES IN BUILDING MAINTENANCE

Despite the fact that the use of ICT solutions in assessing, planning or process execution takes place at a different scale and function, the emerging trend such as using sophisticated or innovative tools and techniques could improve productivity in maintenance activities and have a great potential to redefine and re-engineer the conventional setting. Concerning this, there is scope to manage large and complex buildings with advanced and smart solutions based on advanced ICT (e.g. BIM and CMMS integration) for improving maintenance management on construction sites. There are many researches and literatures in practice and academic regarding these ICT applications in maintenance (including retrofits and monitoring).[3,4] The main applications and scenarios of ICT are developed for the construction industry includes the following:

- BIM-based Facility Management (BIMFM)–to support the 3D CAD-based models for identifying, tracking, coordinating and accessing particular building maintenance into a database system;[18]
- BIM-assisted Facility Management–to provide automatically identifying equipment and facility supporting operational and strategic management of buildings in the design and construction phases;[19]
- BIM integrated Computer-Aided Facility Management (BIMCAFM)–to plan the maintenance activities and monitoring the maintenance operation with a combination of 3D CAD;[20]
- Knowledge BIM-Based System–to use priority in the maintenance planning and strategy for maintenance

execution in the design/construction/operation of buildings using case-based reasoning (CBR);[21]

- Mobile and BIM-based Facility Maintenance Management (BIMFMM)–for the acquisition and tracking of maintenance information and provides an information sharing platform using a webcam-enabled notebook or tablet;[22]

- RFID Localisation and BIM-based Visual Analytics–for location management, tracking of maintenance components in the building;[23]

- Navigation system using BIM and RFID–to locate and navigate any components in an unfamiliar building facility in real-time;[24]

- 3-Dimensional Visualized Expert System–to provide a corresponding building maintenance plan for reference based on the optimisation of maintenance management;[25]

- Defect Management System using BIM, Image-Matching and Augmented Reality (AR)–to detect dimension errors and omissions as well as to enable quality inspection without visiting the real work site;[26]

- Collaborative BIM-based Markerless Mixed Reality BIM3R–to facilitate real-time and on-site data collection and to support inspectors in evaluating building elements using Mixed Reality (MR) as visualisation technique;[27]and

- BIM-based Visual Analytics Approach (Integration with COBIE)/Facilities Management Visual Analytics System (FMVAS)–to identify, assess the root cause (for the specific defect problem) based on the visual analytics for building.[28,29]

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■3.0 CHARACTERISTICS OF BIM TECHNOLOGIES IN BUILDING MAINTENANCE

This section will discuss the various characteristics of the state-of-the-art BIM technologies in terms of how they work and the system stages. There are three primary components of a BIM stage representing transformational milestones along the implementation continuum which separate 'pre-BIM', a fixed starting point representing industry status before BIM implementation, and from 'post-BIM', a variable ending point representing the ultimate goal of employing BIM concepts and tools to achieve Virtually Integrated Design, Construction and Operation (viDCO) as shown in Figure 1:

1. The volume and complexity of changes identified in BIM stages are transformational and requires the object-based modeling, model-based collaboration and network-based integration for reaching a maturity level as defined as the quality, repeatability and degree of excellence within each stage.[30,31] The object-based modelling is consisted of few types of model-based deliverables, such as parametric, algorithmic and other 3D graphical views as well as is normally identified on the software to be offered (e.g. model-based CAD 2D and 3D).

2. The model-based collaboration provides model interchanges and model-linking or federation through a BIM based functional design an ordering process (FDOP) to shorten the latency in collaboration between architects, engineers and contractors and perform rapid information and knowledge exchange in early project design phases.[32]

3. The network-based integration facilitates the multi-user collaborative interaction in distributed systems environment and provides effective technology platform in Architecture Engineering Construction (AEC) industry through the combination of the open data-exchange mechanism and distributed network architecture.[33]
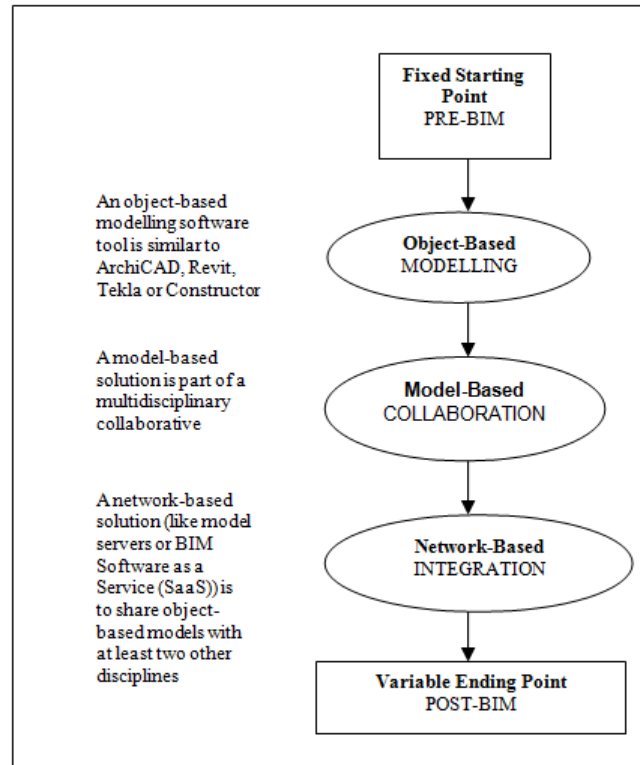

Figure 1 BIM stages (*Source:* Succar *et al.*[34])

The following section explains further the components of the BIM system; the object-based modelling, model-based collaboration and network-based integration.

BIM System Components

Object-Based Modelling

The building information is modelled based on object and are represented as elements in a virtual building. This platform object is identified by an ID number, this ID number is paired with a set of instructions that describes the geometry and also other data associated with the object.[35] The object-based modelling also contain specification, quantities, analytical parts and some extra parts such as cost and sustainability information as well as can be classified in a different way such as demonstrated as an open matrix with variable numbers of objects and variable number of properties for each object. One example of the object-based modelling is where the information and the behaviour of number of column differ from slab in terms of the properties that represent the object.[36]

Object-based modelling can be operated at many forms (e.g. simple or complex) and for many purposes. Every purpose will serve as a base information model for all disciplines, custom workflow processes and custom applications in the areas of: simulation, decision making, the analysis of data and content of building construction in the context of maintenance management

projects.[37] The object-based modelling can generates single-disciplinary models within design, construction or operation as the three project life-cycle phases. Designers and fabricators are taking benefits of using object-based modelling due to save time and automatic in coordinating of 2D documentation and 3D visualisation. However, construction projects by their nature are fragmented, complicated, risky and uncertain. The challenge of the object-based modelling is when using them, in remote construction projects which have their unique problems, resulting in the loss of control over communications and management, including lack of management skills, human resources and building structure.[38,39]

Model-Based Collaboration

Model-based collaboration contains a repository of the building data, allows native applications to import and export files from the database for viewing, checking, updating and modifying the data.[40] According to Jalyzada *et al.*, the model-based collaboration is often called integrated BIM represents a significant paradigm shift in industry practices to enable live collaboration on a centrally shared model and database between all members of the construction supply chain.[36] The data is shared, exchanged and stored between a centralised server (e.g. Industry Foundation Classes (IFC) and Product Life-Cycle Support (PLCS) standard) and versioning information using collaborative and integrated BIM system. The model-based collaboration will enable a transition from 3D CAD visualisation or rendering to interoperable multi-Dimensional (nD) CAD modelling and analysis, which stand for the practice of integrating multi-level professional services on top of a single 3D object CAD model. Interoperability at data level also can effectively reduce fragmentation in interface management and collaboration management in the AEC work flow.[41] The model-based collaboration included object models, representation models and meta information for importing and exporting documents to link building elements and other object types to facilitate the implementation of a predictive Life-Cycle Management System (LMS) and by that improve the feasibility for adopting long-term and dynamic maintenance strategy in the building maintenance management process. The information provided in the structure of LMS and its connection to other business support systems is transformed to an open BIM, with the aid of IFC and PLCS by the model server, which the model-based collaboration as a tool for supporting all types of decision making and planning of optimal design, construction works and systems therein can then be used for data visualisation, simulation and analysis.[42,43]

Model collaboration systems (MCS) such as model servers can exploit and reuse information directly from the models to extend the current intra-disciplinary collaboration towards multi-disciplinary collaboration. Figure 2 shows an example of the MCS which require users and functions to support different use cases for performing a role in the collaboration process.

The focus users range from a large architectural practice, a general contractor to the construction product manufacturer depending on their functionality and perception of future requirements for BIM collaboration. From the MCS, four basic domains have been identified for the functional requirements for multi-disciplinary collaboration on models; these domains are model content management, model content creation, viewing and reporting and system administration. The model content creation domain can supports content creation operations in a Building Information Model to improve the quality of content being created making sure it is suitable for publishing on the central data repository while the model content management domain can provides a higher level of access and permissions to operate on

model content. The viewing and reporting domain can includes tasks like model/multiple model viewing, navigation/walkthrough, clash detection and colour customisation for design discussion or as per client/project requirement. The system administration domain can includes use cases from an IT system administration, organisation or project administration standpoint.[44]
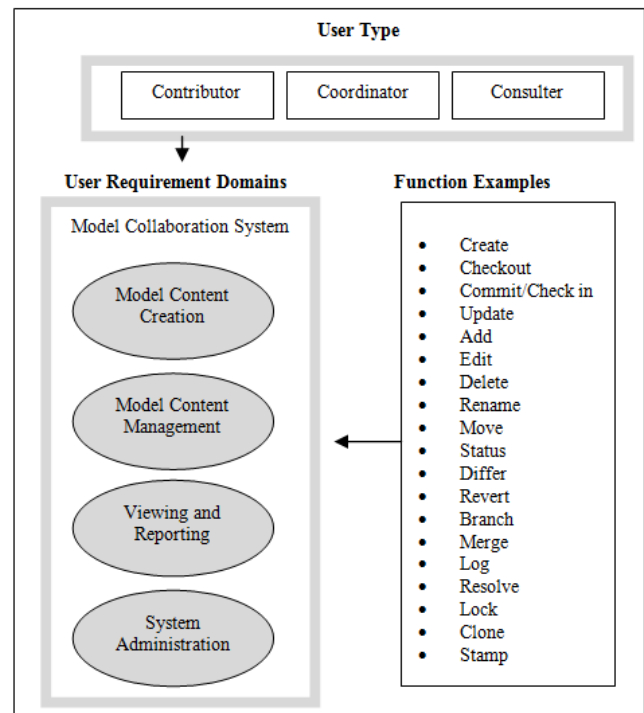

Figure 2 Example of MCS (*Source*: Shafiq *et al.* [44])

Network-Based Integration

Network-based integration is the transition from collaboration to integration and it become interdisciplinary nD models that allow complex analyses at early stages of virtual design and construction.[45] The network-based integration is achieved through model server technologies, single integrated/distributed federated database or SaaS solutions that integrate project activities and all aspects of design, construction, and operation are concurrently planned to maximise the value of objective functions while optimising constructability, operability and safety.[46,47] Platform as a Service (PaaS) and Infrastructure as a Service (IaaS) for the network-based integration has created a way for different applications to openly interoperate and exchange information that provides their service to construction companies with a certain scale to interact between the existing software and other software through the network and put the operating system, middleware, and applications into the network of the virtual machine and the dynamic elastic network infrastructure and platform for both PaaS and IaaS respectively. SaaS come with software features-based data information integration with different functions throughout the whole lifecycle of projects to optimise design, visualise, simulate and share data and processes at any time. The examples of SaaS are Google Apps, Salesforce and Zoho Office.[48]

As mentioned above, BIM stages use network-based integration represented by a 'cloud', usually referring to the Internet where it can be accessed by various devices anywhere and anytime. The network-based integration lies directly upon an SaaS layer providing a post-BIM platform upon which

applications and services can facilitated integrated project delivery targeted for pertinent parties, including architect, engineers, owners and contractors as illustrated in the Figure 1. Figure 3 depicts some other examples of the network-based integration that offer three broad services referred as SPI (Software, Platform, and Infrastructure) contributed to exchange information more effectively and efficiently throughout the building life cycle. The infrastructure resources in IAAS are the separation of management concerns in computing, storage, and networking for supporting complex virtual network topology configuration as well as handling live virtual machine migration (e.g. memory, storage and network connectivity).[49,50]The PaaS platform resources typically include object storage, identity, runtime, queue and databases desired to provide a certain framework and a basic set of functions that users can customise and use to develop their own applications and transfer to other customers through their server and Internet. The SaaS resources in the top layer are more suitable for delivering the selective software and application functionality (e.g. monitoring, content, collaboration, communication and finance) as a service include centralised configuration, software release updates without requiring reinstallation and accelerated feature delivery.[48,49,51]
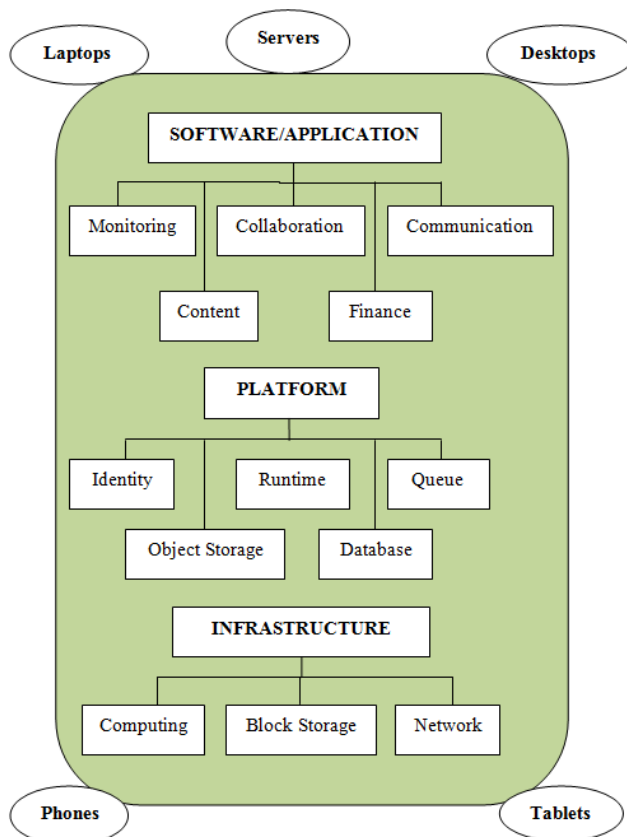

Figure 3 Example of Network-Based Integration in a Cloud-Based Deployment (*Source:* Jalaludin *et al.* [49])

■**4.0 POTENTIAL BIM TECHNOLOGIES APPLICATION AREAS IN BUILDING MAINTENANCE**

Many researchers have shown the potential of software applications in various areas of the construction industry including maintenance management that can be enhanced by using the latest technology for information sharing and communication as listed follows:

- BIM-based Facility Management (BIMFM)–to enhance progress maintenance monitoring and quality inspection efficiency;[18]
- BIM-assisted Facility Management–to bridge the communication gap between design and facility management professionals on a database level;[19]
- BIM integrated Computer-Aided Facility Management (BIMCAFM)–to improve building analysis, energy efficiency and sustainability as well as collaboration using Integrated Project Delivery (IPD);[20]
- Knowledge BIM-Based System–to improve preventive/corrective maintenance strategies and planning;[21]
- Mobile and BIM-based Facility Maintenance Management (BIMFMM)–to provide a real time service platform and support quality control efficiency during the maintenance management process;[22]
- RFID Localisation and BIM-based Visual Analytics to support real time maintenance tracking and improve inventory management control;[23]
- Navigation system using BIM and RFID–to increase inventory accuracy, simplify maintenance work processes, save valuable time and money;[24]
- 3-Dimensional Visualized Expert System–to reduce time, labour, and financial expenses, as well as further enhance component reliability;[25]
- Defect Management System using BIM, Image-Matching and Augmented Reality (AR)–to prevent building work defects proactively, save inspection time and reduce rework related costs at construction sites;[26]
- Collaborative BIM-based Markerless Mixed Reality (BIM3R)–to facilitate the inspection operations and maintenance schedule of a building;[27]and
- BIM-based Visual Analytics Approach (Integration with COBIE)/Facilities Management Visual Analytics System (FMVAS)–to provide defect detection and diagnosis solution in order to formula effective corrective and preventive maintenance plans.[28,29]

Table 1 shows five (5) current BIM systems that are selected based on major functions in the comparison over current technologies where there is the same gap among those systems which is the defect diagnosis and decision making support function.

Table 1 Comparison of maintenance management technologies

No	BIM Systems / Functions	BIM CAFM	BIM CMMS	BIM RFID	BIM EXPERT SYSTEM	BIM AR
1	Asset Inventory & Registration	Yes	Yes	Yes	Yes	Yes
2	Work Order	Yes	Yes	Yes	Yes	Yes
3	Asset Management	Yes	Yes	Yes	Yes	Yes
4	Defect Inspection	Yes	Yes	-	Yes	Yes
5	Complaint Management	-	Yes	Yes	Yes	Yes
6	Maintenance Estimating	Yes	Yes	Yes	Yes	Yes
7	Maintenance Coordination	Yes	Yes	-	Yes	Yes
8	Energy Management	Yes	Yes	Yes	Yes	Yes
9	Labour Management	-	Yes	Yes	Yes	Yes
10	Financial Management	-	Yes	Yes	Yes	Yes
11	Quality Control	-	Yes	Yes	Yes	Yes
12	Maintenance Planning/Scheduling	Yes	Yes	Yes	Yes	Yes
13	Decision Support in M&E Diagnosis	-	Yes	-	-	-
14	Decision Support in Concrete Diagnosis	-	-	-	-	-
15	Report & Statistic	Yes	Yes	Yes	Yes	Yes

5.0 CURRENT TECHNOLOGICAL CHALLENGES

The expansion of current technologies is to assist the maintenance management processes using BIM-based system. The processes start from identification, defect diagnosis, maintenance planning and execution of the facilities.[52] The defect diagnosis in maintenance management becomes as challenges for storing and delivering quality assessment 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 organization.[53] Effective management of maintenance diagnosis relies on the sophisticated technology in ensuring the successful of dependability building facility and to achieve the expected return on investment in maintenance (ROIIM).[54]

Another challenge for BIM technology is to provide the adequate strategic decision making to analyse information in improving the maintenance project outcomes (cost, time, quality, safety, functionality, maintainability, etc.).[55] Most research on BIM in Malaysia has been focused on developing regulations and policies, application of BIM, solving technical problems, and searching for the value of BIM. However, the use of BIM in Malaysia during IBS building maintenance for decision-making has not been thoroughly reported in Malaysia yet. One may be wondering then if BIM is indeed well utilised in Malaysia during IBS building maintenance for practical decision-making.[56] Specifically, the use of BIM for scheduling, estimating, coordination, review of drawings, and tracking for change orders were carefully monitored and compared with the industry expectations as they were addressed in the literature.[18,37]

The developed model of decision making support quantifies the overall condition properly and evaluates the possible alternatives regarding selecting a solution for building improvements.[57] A few researchers have considered IBS to provide more efficient decision support tools in assessment such as 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 existing tools consider inadequate aspects of sustainability.[58] 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 assessment guidelines and tools are only used after the design of the IBS building project is about to be completed.[59] Due to unavailability for strategic decision support tools in assessment for IBS construction industry using BIM, it is desirable to develop a computerised integrated project delivery (IPD) with decision support for BIM. The BIM technology associated with IPD during the design phase is to improve the quality of decision with the precise and comprehensive information based on technology application used to generate critical assessment information about a proposed design, including cost estimates, energy-use analysis, structural details, etc.[59] Therefore, the current technology challenges append the competition in the market for emerging of the managerial decisions technology of ICT-based system that focuses on improvement of complex maintenance management processes such as defect diagnosis and decision making process which most organisation need.[60]

6.0 CONCLUSION

Majority of the current implementation of ICT in maintenance management processes mainly focus on the traditional design approach with little emphasis on decision making and defect diagnosis tools. The traditional approach means that all the design and construction process will be conducted in 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).[21,61] Modern developments in ICT technology related to 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. However, the solution of a shift from fragmented into more integrative way of construction management is an immense technological promise based on the potentiality of emerging innovative methodologies such as BIM. BIM can assists 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. A focused research in a more comprehensive area is desired for more effective application of BIM in defect diagnosis and decision making. This review has highlighted that BIM is a potential method in maintenance management on IBS buildings in Malaysia.

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