SEMARAK ILMU PUBLISHING
202103268166(003316878-P)

Journal of Advanced Research in Applied Sciences and Engineering Technology

Journal homepage:
https://semarakilmu.com.my/journals/index.php/applied_sciences_eng_tech/index
ISSN: 2462-1943

Using BIM Technology to Inspect Building Defects Improves the Maintenance Performance of Buildings: Literature Review Systematic

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ABSTRACT

BIM technology can help maintenance buildings and facilitates the inspection buildings defects on structures and infrastructure ready. There are benefits of BIM for maintenance buildings including the ability to provide management information, integration design form and delivery projects that can be managed. Defects and damages building defined as failure against the ability building for delivery required services. The traditional method of maintenance built in team through a series of documents such as drawing, 2D plans, specifications and manuals still for operation and maintenance building make performance engineering maintenance for building government not effective and not satisfactory. This research conducted for study implementation BIM technology against inspection of building defect for increasing performance service maintenance building. Analysing this with PRISMA (review systematic pre-investigation and meta-analysis techniques), published guidelines for research literature systematic (SLR) run. Paper work mainly on this topic is published between 2011 and November 2022 was reviewed. After reviewing nine publication journals, research trends, methods, methodologies, gaps and related future goals with BIM in monitoring and maintenance already known. Basically, BIM has interest due to the use of extensive tools in industry building, engineering and construction for the control and management of information of building defect and condition of structure

Keywords:
BIM; technology; building defect inspection; building maintenance

1. Introduction

It is important to assess the current condition of the damaged structure to quickly identify the nature of the defect and develop an effective repair plan [1]. Management of maintenance building makes it easier to monitor and evaluate structural characteristics, reducing structure maintenance costs and improving structural safety [2]. Structures respond differently to various stresses over the course of life, which is a good management system can evaluate for determining the characteristics

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https://doi.org/10.37934/araset.57.2.5369

and components that change are taken from [3, 4]. Therefore, structural observation and measurement, condition assessment, information management, design and fabrication decisions, repair implementation, evaluation performance repair and maintenance are an important stage in structural damage assessment [5, 6]. Problem invalidity building due to construction defects, material defects, defects quality of work and aging building. Examples of construction defect criteria include concrete in the structure, damaged floor tiles, damaged ceilings, collapsed drains, leaking pipes, cracks in the foundation, mold on the foundation and solution on the foundation [7].

Unfortunately, from the previous studies [8-10] show that government maintenance techniques for buildings are ineffective and unsatisfactory. These findings show the importance of proper maintenance management for public buildings (e.g., schools, offices, and hospitals) to maximize the value of the budget allocated to public facilities and extend the life cycle of buildings. Three main problems have been identified in the maintenance of buildings: Structural damage, construction defects and a poor building environment [11]. In addition, financial resources, speed and accuracy, poor team management and weak performance design affect building maintenance performance [12].

However, the main problems in building maintenance are the use of traditional systems for maintenance management, including paper-based reports and disorganized databases. Project delivery, planning, surveying, procurement, and monitoring are all part of the maintenance process. Therefore, BIM can play an important role in automating construction maintenance operations to be more effective and faster. The two most important aspects of building condition assessment during building maintenance monitoring that can be improved through the applications of BIM are speed and accuracy. Building data modeling has shown great promise for the construction sector. Information about building defects can be made more accessible, useful, and understandable through BIM. Modeling can improve facility monitoring standards and management practices [13-16].

BIM is a digital expression of a facility's physical and functional characteristics that is shared and delivered throughout the life cycle of project planning, operations, and maintenance through the integration of building data and information models [17]. Since different data are usually generated or associated with different activities during the project lifecycle, data integration with BIM has been identified as an important way to better manage and leverage data for project management. Integration of BIM models with different types of data, such as safety monitoring data, structural geometry, and material properties, was done to effectively manage data throughout the project [14]. Similarly, mapping or integrating condition data into BIM models has the potential to provide a more comprehensive understanding of the condition of specific components and facilitate maintenance planning decision making. Most of the detected failure information is only used to generate reports and is not stored in a digital model for systematic and object-oriented management. Although BIM is widely used in building management, there is still little mapping between the real world and BIM models to manage building or structural conditions in real time [17].

Combining BIM object-oriented management with real buildings or structures can further promote the application of non-destructive testing and further improve the efficiency of detection and management. Therefore, it is necessary and feasible to take advantage of the object-oriented management capabilities in BIM to map real-world detection results to the BIM model for integrated management [18]. There is a need to quickly integrate inspection results into model functions and document them in the BIM environment for use and to improve their visualization, accessibility, and communication. Furthermore, there is a lack of effective and automated methods to integrate the as-is state into BIM compatible models. Managing and controlling maintenance data, improving interpretation by integrating real-time data or based on construction drawings into BIM models, and providing a reliable database for various projects can be summarised as the effectiveness of using BIM in building maintenance. Although BIM maintenance monitoring programs and techniques have gained widespread recognition over the past two decades, important questions regarding the use and importance of building information models in building maintenance monitoring still need to be answered. These questions include the methods are used to identify construction defects, the latest issues and advanced techniques in construction defects and the future plans in this field.

2. Methodology

Most recent studies refer to systematic reviews conducted around the world. However, in Malaysia, several studies have been conducted as part of a comprehensive review of building defect audits [19]. This section addresses the need for a holistic review of the state of building maintenance in Malaysia. The next section presents the methods used to answer the research questions of this study. This review is divided into three parts, the first three steps being inspection of deficiencies, knowledge of building maintenance, and problem solving. An in-depth examination of the occurrence of sub-problems and methods of resolution is also included. Studies and explanations of specific measurements and methods are covered for a better understanding of building maintenance in Malaysia. In the next section, the scientific literature is carefully reviewed and summarized to identify, select, and evaluate the most relevant studies on building maintenance [20]. The last point suggests how to solve the problem of screening potential researchers. This analysis used PRISMA (pre-recorded systematic review and meta-analysis techniques), a published guideline for conducting a systematic literature review (SLR). In general, publication guidelines are necessary to assist authors in assessing and verifying the accuracy and thoroughness of the review with relevant and important details. Randomized review of study evaluations which can be a critical component of reporting systematic reviews for other types of studies is another aspect of PRISMA that is highlighted [21].

2.1 Identification

Methodology for a comprehensive review of all work related to the inspection of building defects from a building maintenance perspective. Web of Science and Scopus were reviewed for the searches conducted on November 22, 2022. Both of these databases have collection quality journal height by using a difficult selection process. For each article must regularly describe specific. In selecting a set of papers suitable for this report, the systematic review consists of three main stages. The first step is to identify keywords and search for related and similar terms based on thesauri, dictionaries, encyclopedias and previous studies. Selected keywords related to the desired study conducted as well as follow to determine the scope of work that will be conducted in the future. In relation to that, after all relevant keywords were determined, search strings were created in Web of Science and Scopus as shown in Table 1. In the first phase of the systematic review, 25 papers were already found from both databases, as shown in Figure 1. Figure 1 shows the flow diagram of screening, eligibility, data summarization and analysis leading up to the inclusion of the selected papers.

Table 1

The search string

Scopus	TITLE-ABS-KEY (("defect" OR " faulty") AND building AND information AND modelling AND ("building maintenance" OR "facility management")) AND (LIMIT-TO (PUBSTAGE , "final")) AND (LIMIT-TO (PUBYEAR , 2022) OR LIMIT-TO (PUBYEAR , 2021) OR LIMIT-TO (PUBYEAR , 2020) OR LIMIT-TO (PUBYEAR , 2019) OR LIMIT-TO (PUBYEAR , 2018) OR LIMIT-TO (PUBYEAR , 2017) OR LIMIT-TO (PUBYEAR , 2016) OR LIMIT-TO (PUBYEAR , 2015) OR LIMIT-TO (PUBYEAR , 2013) OR LIMIT-TO (PUBYEAR , 2011)) AND (LIMIT-TO (SUBJAREA , "ENGI") OR LIMIT-TO (SUBJAREA , "COMP") OR LIMIT-TO (SUBJAREA , "BUSI") OR LIMIT-TO (SUBJAREA , "SOCI")) AND (LIMIT-TO (LANGUAGE , "English")) AND (LIMIT-TO (SRCTYPE , "j"))
Web of Science	TS= ((“defect” OR “faulty”) AND building AND information AND modelling AND ("building maintenance" OR "facility management"))

2.2 Screening

In the first screening phase, duplicate publications were ignored. In the second phase, sixteen publications have already been screened based on a set of inclusion and exclusion criteria defined by the researcher, while nine articles were excluded in the first phase. The first criterion is literature, as it is the main source of useful knowledge. In addition, publications in the form of systematic reviews, meta syntheses, book series, books, chapters and conference proceedings were excluded from the current study. Furthermore, this study is limited to English-language studies. The time frame was chosen for a period of eleven years (2011–2022). All selected articles were screened according to the following criteria, as shown in Table 2.

Table 2
The selection criterion is searching

Criterion	Inclusion	Exclusion
Language	English	Non-English
Time line	2011-2022	< 2011
Literature type	Journal (only research articles)	Journal (book chapter, conference proceeding)
Subject area	Engineering, computer science, business, management and accounting, social science	Besides engineering, computer science, business, management and accounting, social science
Publication stage	Final	In press

2.3 Eligibility

The third step, the so-called qualification, requires the creation of 13 articles. In this step, all article titles and main texts are carefully reviewed to ensure that they meet the inclusion criteria and the research objectives of the present study. Four papers were already excluded because they were not purely scientific papers based on empirical data. Nine papers were finally made available for analysis.

2.4 Data Abstraction and Analysis

In this study, an integrative analysis of one of the research techniques was conducted to analyze and synthesize the different research designs (qualitative, quantitative and mixed methodology). The expert-led research focused on creating relevant themes and subthemes. The data collection phase is the first step of theme development. Nine papers were carefully reviewed by the authors for assertions or details that addressed the issues raised in this study. After analyzing the study of building defects inspection and BIM development, the authors and professionals form an important group. The three main outcomes of this strategy are defect inspection, building maintenance knowledge and problem solving. The author then elaborates on each assigned topic and explains any related issues, ideas or concepts. The corresponding author has worked with other co-authors to develop a topic based on the results of this study.

In this case, logs are kept throughout the process of data analysis to record any analysis, viewpoints, puzzles, or other ideas related to data interpretation. The authors also compared the results to account for any discrepancies in the formation of themes. It should be noted that the author highlights any inconsistencies in the concepts. Both search results were combined into one list, excluding literature reviews and duplicate articles, resulting in 278 articles that matched the research topic. After reading the articles, they were categorized into different groups depending on the topic. Since the use of BIM in building maintenance inspection is a new topic for researchers, there is no comprehensive approach to a specific topic. Therefore, articles related to BIM in disabled building defects inspection from the aspects of maintenance and monitoring were also reviewed. A flowchart of the proposed search study and PRISMA SLR is shown in Figure 1.

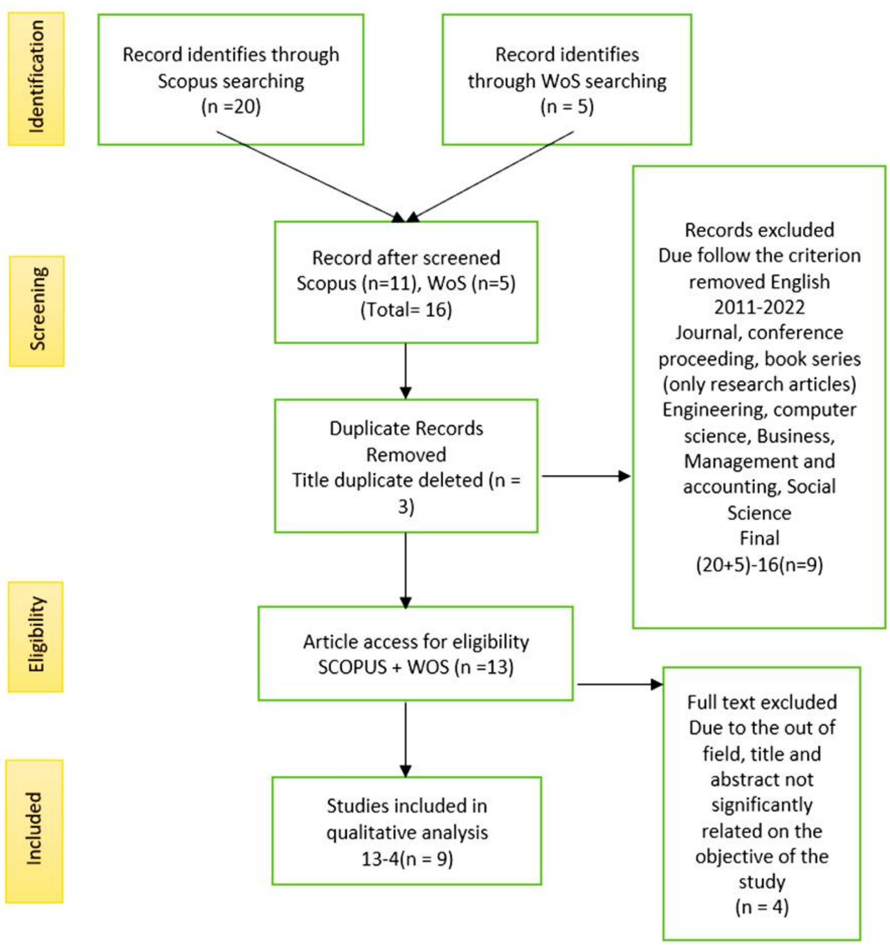

Fig. 1. Flow diagram of the proposed searching study [21]

3. Results

This section aims to cover all concepts related to the monitoring and maintenance of building defects using BIM. Future work by researchers following previous studies is mentioned at the end of each issue. Based on the search technique, nine articles were extracted and analyzed. The three main themes of defect inspection, building maintenance knowledge (three articles) and problem solving were used to categorize all articles. Table 3 shows the results of the research articles based on the proposed search criteria.

Table 3
The research article finding based on the proposed searching criterion

No.	Authors	Title	Year	Source title	Themes
1	Chow, J.K., Liu, K.-F., Tan, P.S., Su, Z., Wu, J., Li, Z., Wang, and Y.-H.	Automated defect inspection of concrete structures	2021	Automation in Construction	Defect inspection
2	Eskandari, N., Noorzai, E.	Offering a preventive solution to defects in commercial building facility system using BIM	2021	Facilities	Defect inspection
3	Ismail, Z.-A.	How BIM systems affect maintaining IBS building	2020	Facilities	Building maintenance knowledge.
4	Ismail, Z.-A.	Implementation of BIM technology for knowledge transfer in IBS building maintenance projects	2020	International Journal of Building Pathology and Adaptation	Building maintenance knowledge.
5	Ismail, Z.-A.	Lesson learned in maintaining the precast concrete buildings	2020	Journal of Facilities Management	Building maintenance knowledge.
6	Xu, Z., Li, S., Li, H., Li, and Q.	Modeling and problem solving of building defects using point clouds and enhanced case-based reasoning.	2018	Automation in Construction	Problem solving
7	Ismail, Z.-A.	Improving conventional method on precast concrete building maintenance Towards BIM implementation.	2017	Industrial Management and Data Systems	Problem solving
8	Chen JJ, Lu WS and Lou, JF	Automatic concrete defect detection and reconstruction by aligning aerial images onto semantic-rich building information model.	2022	Computer-Aided Civil and Infrastructure Engineering	Defect inspection
9	Hamledari, H; Azar, ER; McCabe, and B	IFC-based development of as-built and as-Is BIMs using construction and facility inspection data: Site-to-BIM data transfer automation.	2018	Journal of Computing in Civil Engineering	Problem solving

3.1 Defect Inspection

Building defect inspectors have the important task of ensuring that buildings that are bought, sold or occupied are safe and comply with current regulations. The main objective of any building inspection is to identify defects and deficiencies in the building and produce a comprehensive report. A hierarchical system for data acquisition, defect identification, scene reconstruction, defect evaluation and data integration are useful for automatic defect inspection of concrete structures [21]. Based on this statement, the development of mobile data acquisition devices with 360° cameras and digital Light Detection and Ranging (LiDAR) enables highly flexible imaging and three-dimensional (3D) spatial data acquisition as the user moves through difficult indoor situations. Simultaneous localization and mapping techniques are used to reconstruct locations from captured LiDAR data, and deep learning algorithms are used to effectively detect defects from captured photos. However, the condition of the defect is assessed based on the detected defect image and defect dimensions estimated from the matched image and LiDAR data. It is also possible to detect damage and assign its position to the corresponding component [22].

For better building management, all inspection results are entered into existing building modeling files. Therefore, the proposed workflow has successfully demonstrated the use of advanced technology to facilitate public infrastructure inspection programs by validating it against case studies of cracking in concrete and identifying spalling in real assets. Figure 2 shows the framework for automatic defect inspection of concrete structures.

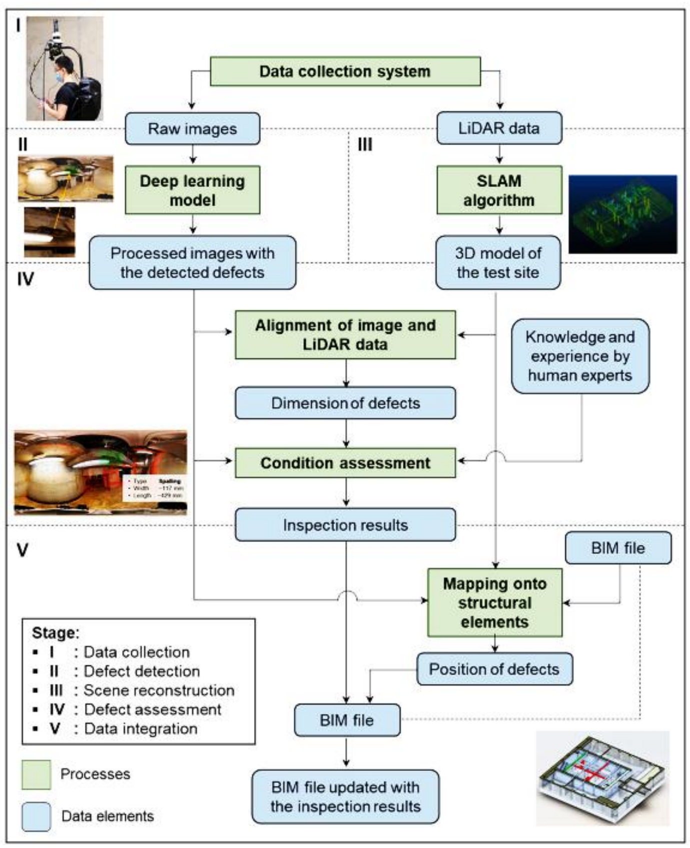

Fig. 2. Framework for automated defect inspection of the concrete structures

The entire workflow is mainly divided into five stages, i.e., data collection, defect detection, scene reconstruction, defect assessment and data integration stages [21]. For example, a straight line in a square image can be displayed as a curved line at different points. In addition, the perspective projection distortion impairs the detection of concrete damage [23]. A checkerboard target was used for calibration and the instructions of the MATLAB camera calibration tool [24, 25] were followed. Therefore, it was found that the error does not affect the detection of concrete damage. Eskandari [26] stated that commercial building systems are expensive and although they require complicated operation and maintenance, some failures can cause significant and permanent damage.

BIM is used in a variety of ways for building maintenance. A comprehensive BIM model is then used to discover and investigate processes and tools for the operation and maintenance of the system during its operational life [27]. The result is a subset-based correction proposed by Total Productive Maintenance (TPM) that successfully prevents system failures during operation and maintenance periods. Facility managers can take action based on TPM to prevent failures by evaluating the results via an integrated BIM platform. Information about specific defects and damage is important for building maintenance [28]. Computer vision is increasingly being investigated for the automatic detection of defects in concrete structures. In addition, there is not enough research on 3D reconstruction of defects to determine their location and geometry. Therefore, a unique computational method for identifying and reconstructing concrete defects using geotagged aerial images is proposed to overcome this limitation. A set of aerial images is matched with a building data model using a bundle registration method.

The register enables the semantic search for materials to identify areas of interest for defect detection in BIM. It helps to match aerial camera locations and enables accurate reconstruction of defects. Experiments show the effectiveness of the strategy by providing sections over the unit that are 6.4% higher than conventional methods, while the false discovery rate was drastically reduced from 70.8% to 56.8%. The defect geometry was successfully reconstructed in 3D space. By utilizing the extensive data from BIM, this study creates new opportunities to improve defect detection. A scaled implementation of this method can support numerical simulations, urban regeneration and other smart applications. Previous studies have shown that it is important for maintenance management to have a plan to detect building defects and that a comprehensive inspection is important to gather information. Supporting advanced and innovative technologies is just as important as detecting and repairing defects in concrete structures. It can make the work efficient, effective and safe while reducing maintenance costs.

3.2 Building Maintenance Knowledge

Inspection, repair and maintenance of defects in buildings are usually part of the normal scope of building maintenance. This technique shows how it can be used for IBS building management in the context of Malaysian maintenance practices as stated by Ismail [29]. Currently, maintenance management techniques affect the effectiveness of building management in Malaysian industrial building system (IBS) and tall buildings. The conventional approach has led to many problems including poor service delivery, limited funding, inefficient staff and repetitive errors (paper-based forms) [30]. The data shows that there is a need to digitize maintenance management for complex and tall IBS structures. The methods used to conduct this qualitative study were semi-structured interviews and literature review. Code and data flow diagrams are used in the development of computerized systems, and then system prototypes are tested. The evaluation of the maintenance work showed that problem identification and control of IBS structures became easier, faster and cheaper by implementing this prototype system [31]. Prototyping systems can improve the effectiveness of maintenance management for IBS components by reducing the risk of design errors, e.g. calculation errors. The efficiency of complex IBS building construction projects in Malaysia is hampered by the country's current maintenance management system [32].

This work focuses on the integration of BIM to improve the transfer of knowledge about the deterioration and deficiencies of IBS components in IBS building maintenance projects. Vaha *et al.,* [33] mention that maintenance organizations use various computerized systems, including building automation systems and monitoring and data acquisition systems. Furthermore, it is stated that IBS building defect maintenance has not yet adopted BIM technology. This is therefore the basis for the development of BIM prototypes, expert systems and computerized maintenance management systems. The creation of this new system will improve the integration of BIM technology and expertise in the diagnosis of IBS components. Figure 3 shows that the process proposed by the BIM-based CMMS expert consists of three elements: fault reporting and assessment, fault diagnosis and mitigation. BIM-based platforms are considered particularly suitable for the development of larger, complex and high-rise building systems [34]. Vaha *et al.,* [33] stated that it has been investigated whether effective operation and maintenance, especially in complex projects can be achieved by identifying potential defects and rework using a BIM-based platform.

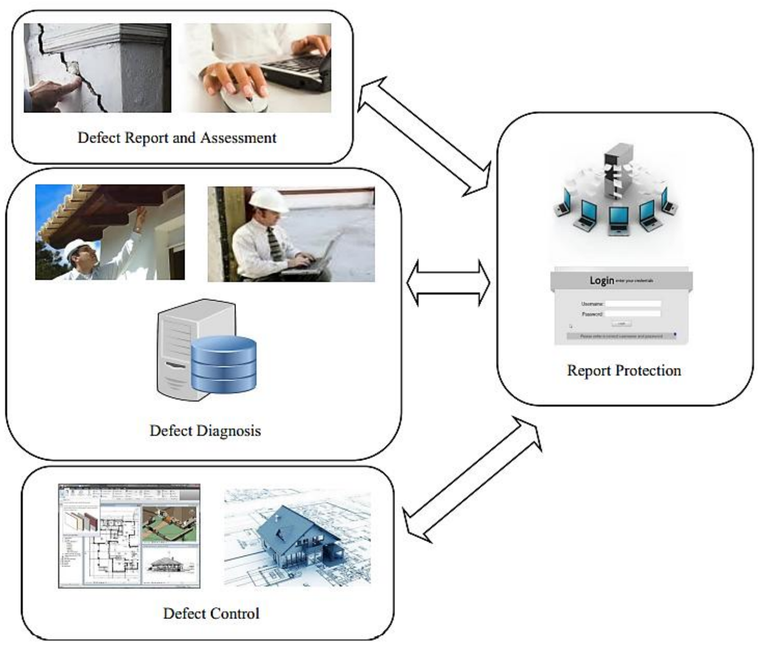

Fig. 3. Components of MMS [34]

Ismail [32] has also pointed out current problems in the maintenance of defects in precast concrete elements and suggested remedial measures. One of the problems in the current practice of conventional methods in the maintenance of PC structures is the lack of aesthetics and PC structure, the lack of integration between maintenance systems and the lack of intelligent ability to combine fault diagnosis operations in maintenance. In addition, it is also effective in handling information and integrating data from maintenance components into site handling activities [35]. Currently, mainly traditional techniques are used in maintenance management, with little role for decision support and fault diagnosis as shown in Figure 4.

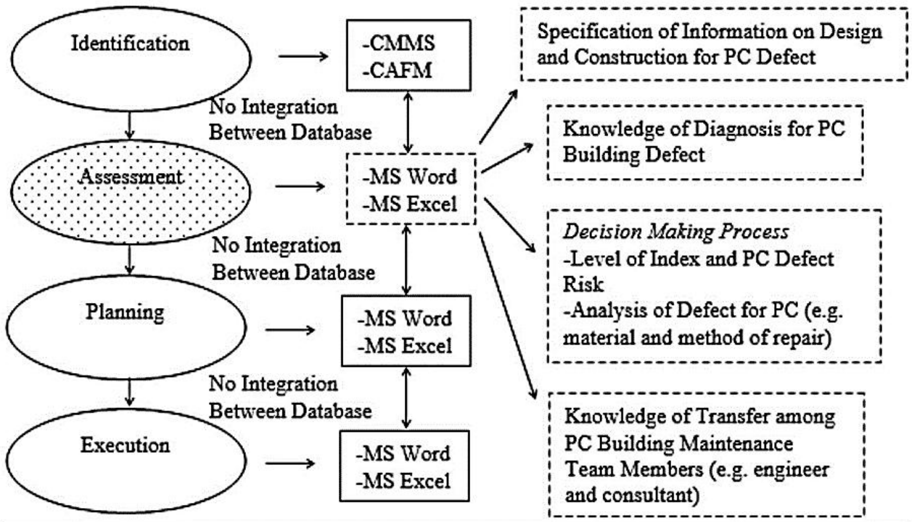

Fig. 4. Key problems for PC building maintenance management practices [32]

Researchers have found in several studies that there are problematic situations, namely the repetition of obstacles such as leaks, joints and cracks. Also, poor work by contractors who need sophisticated tools to solve problems. The use of ICT tools in the new system is now essential to achieve significant budget savings, time planning and other benefits, including reliable data capture for handling diagnostics and defect control. It is therefore recommended that BIM is adopted to reduce the incidence of defects in the design specifications and construction procedures for structures and facilities.

3.3 Problem-Solving

The primary data source for integrated information management for shallow construction defects is the point cloud model. Obstacle features used in multi-criteria decision making are included. Case-based reasoning (CBR) techniques that consider case-based distances improve the performance of case queries and similarity calculations. In the data processing phase, a case-based distance model is used that focuses on a concentrated set of cases with the best options. In the retrieval phase, this tactic can have the advantage of extracting more useful insights from the classified cases. By comparing CBR queries with unrecorded sample data to detect patterns, the effectiveness of computational approaches to evaluate case similarity is supported by preprocessing categorized construction defect information [36].

Based on the results, the proposed strategy is a good way to categorize different construction defect features and avoid ambiguous results from disconnected subsets. This approach is suitable for researching current building maintenance problems in the fields of architecture, engineering and construction [37]. To improve the efficiency of extracting effective information about various cases from the superficial construction defect case database, the cases are collected and a case-based reasoning analysis is conducted for a specific group of cases to reduce the difficulty of describing complex defect cases and prepare for updating the case database. In the database of cases for superficial construction defects, key attributes can be extracted according to the hierarchical structure of the domain ontology for construction defects to classify all cases into groups [38]. In addition, considering the key attributes, new non-grouped defect patterns are recorded in the defect database and sorted into groups to support the case-based analysis. The four processes each include some more specific steps, as described in Figure 5.

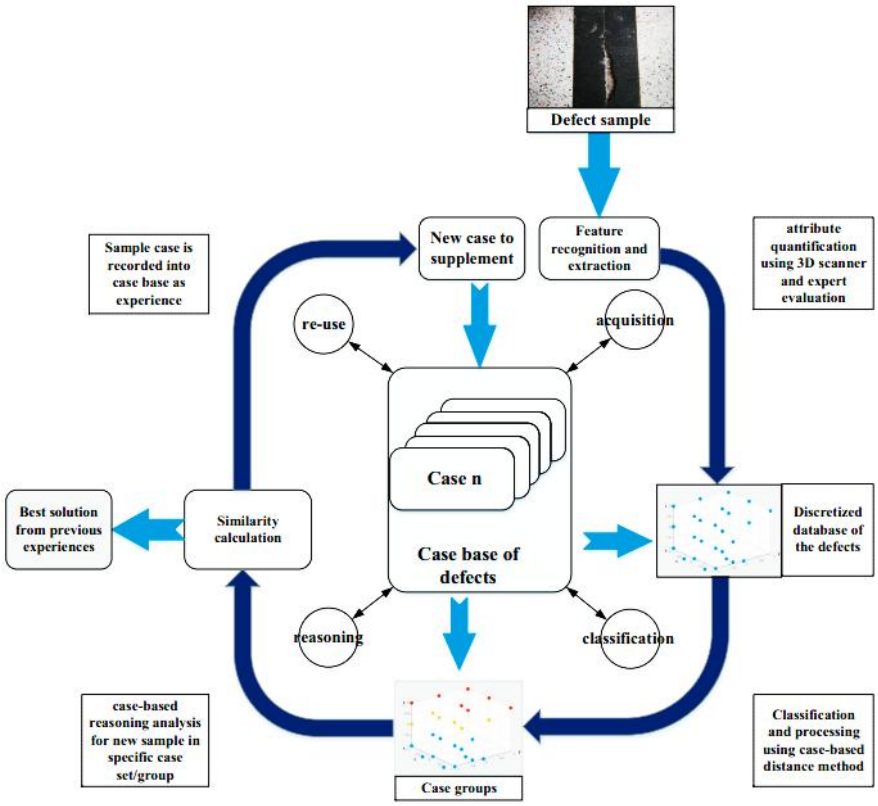

Fig. 5. CRB circle for superficial building defects [39]

Meanwhile, Ismail [40] examined the concept of PC element management in the context of Malaysian maintenance practice. Many PC owners and contractors of building maintenance projects face numerous challenges arising from poor service delivery, ineffective contractors and recurring problems [41]. However, standard techniques are often ineffective in Malaysian PC construction. While the basic approach supports making diagnostic decisions and maintaining current maintenance quality, front-end techniques take advantage of evolving technology, effective control of building performance-based scheduling and monitoring of maintenance work on damaged components [42]. Effective building management and maintenance of a project's construction defects requires accurate and proactive inspection of structural assets for defects and compliance with design specifications. To more accurately reflect the actual conditions on site, the BIM for the project needs to be updated regularly.

However, traditional methods rely on manual updates, are expensive and error-prone, and do not integrate site data into the model [43]. Hamledari [44] stated that a reliable method for automatically updating the BIM model was described, which was developed based on site observations for inspected components using the Industry Base Class (IFC) schema. Information is provided about the type of object inspected as well as inspection details (e.g. defects or changes found, responsible person, type of construction, images taken and time and date of inspection) [45].

The IFC data model is updated with new semantics based on the results of the conflict analysis, changing object types, features and 3D shape representations. Inspection details and user input are automatically captured and mapped to objects in BIM to facilitate diagnosis and possible traceability. This provides a method of capturing reality and facilitates the transfer of data from the site to BIM [46]. Although existing software applications can support the integration of inspection data into BIM, this is a time-consuming and manual process. When using the software, the modeler must identify discrepancies between the design information and the built condition and make updates, as shown in Figure 6.

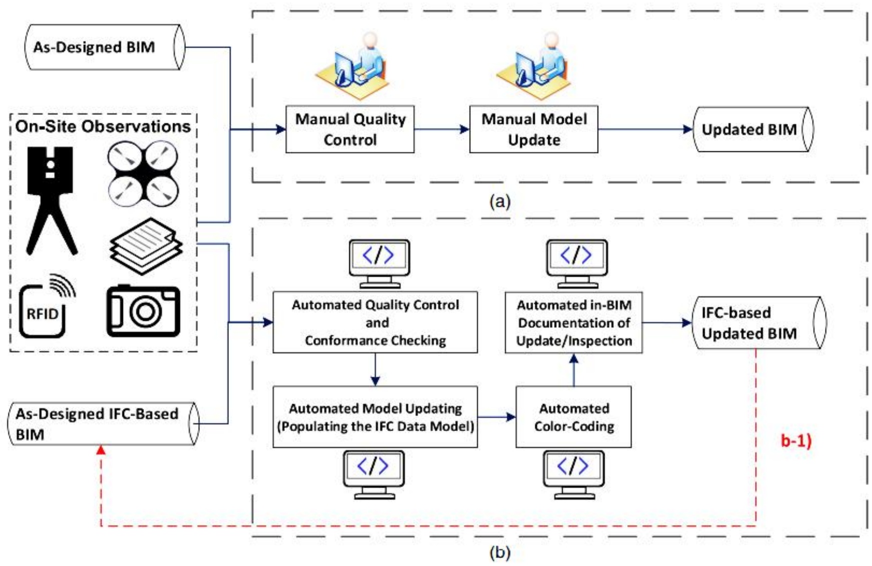

Fig. 6. Comparison of (a) conventional, time-consuming and manual model updates; (b) IFC-based and automated approach [45]

To summaries, the most typical obstacle to efficient building maintenance management is problem solving for building defects inspection. Overall, the traditional or technical methods for investigating and identifying building defects are diverse. However, the studies conducted have shown that BIM is one of the modern technologies being used. Data on building defects from a maintenance perspective is captured in the model created with BIM. By incorporating design changes into BIM, model accuracy can be maintained throughout the construction process. Therefore, all maintenance management teams should consider BIM models and as-built drawings as references and guidelines for effective building defect management.

3.4 Discussion

One way to address the lack of efficiency in solving the problem of building defects in building maintenance management is to use BIM, whereby the building information model fully captures the condition of the project building and includes the necessary drawings and associated design data. BIM is also a process and technology used to create models [47]. The importance of building models for maintenance management in traditional methods is that the maintenance management team receives a set of documents including drawings, two-dimensional plans, specifications, manuals and 3D building models when they are ready to operate and maintain the facility [48]. However, such documents are often incomplete and very difficult to understand and they may not be compatible with the maintenance software. If the information is not included in the building data model, 3D building models for design, analysis, construction planning, four-dimensional coordination and fabrication can support daily operations and planning. In this way, a building maintenance team can ensure reliable and efficient operations. Due to many factors such as repetition and lack of staff, building management is still inefficient. This affects users, finances, time and even safety.

In order to improve the management of building maintenance and easily solve the problem of building defects inspection, BIM must be able to process the data in the system with the interaction between employees. For example, engineers first diagnose certain defects in structural components of traditional or prefabricated buildings and communicate these findings to designers, who then analyze the requirements by examining the impact of their design decisions and the contractor's ability to perform the work safely. BIM can also generate relevant data, such as pre-construction data through to as-built specifications and post-construction/operation data for accurate risk assessment of construction defects as part of the defect control process [49]. In general, the builder is liable for all identified construction defects during the defects liability period (DLP) stipulated in the construction contract with a minimum liability period of 18 months and a maximum liability period of 24 months.

In addition, the BIM model created documents the built reality. The model can be maintained and updated during the construction phase by making changes to the design. The BIM model created serves as the basis for six-dimensional (6D) technical building management, which can be used to integrate all the data required for the management tools into the building management model. It helps with the exact positioning of cables, pipes, devices and other elements, saving time and materials. As-built modeling also helps to identify building materials and existing structural elements, as well as the exact placement of equipment such as pipes and ducts. Therefore, it also saves time and resources by helping with project management and renovation work [50].

BIM can capture a variety of data during the lifecycle of a project, such as information about structures, mechanical and electrical installations and construction costs. In addition, depending on the location of the data, it can determine the exact coordinates of an object and retrieve them when needed. Data that changes over time can be stored in a database and used for specific purposes by performing calculations. In many cases, BIM databases can support the effectiveness of error control in information databases by integrating them with record modeling and design condition indices. This extends service life and reduces maintenance requirements. In addition, reliable design information and corrective actions based on design defect controls and specifications can reduce the time spent on design defect analysis. For example, engineers claim that poor design is responsible for cracks in the walls of the structure. The lack of continuity in the application of failure data and the degree of objectivity in maintenance decisions are the two main problems with this limitation. Nonetheless, the flow of building defect data should technically be linked to a three-level perspective that includes information collection, verification and reuse. Therefore, this study shows that BIM can be used to monitor, identify and record data on building defects throughout the liability period (DLP) and throughout the maintenance of the building.

4. Conclusions

This study presents a systematic review of BIM applications in maintenance management monitoring, particularly building defect issues. In general, 9 papers published between 2011 and 2022 were selected. Data analysis revealed that most relevant publications have appeared in the Journal of Automation in Construction and Infrastructure. The benefits of using BIM to identify building defects in maintenance management aspects are discussed in this paper. About 92% of the analyzed publications were published in the last 11 years which shows a large number of research papers on the use of BIM for monitoring and maintenance.

When analyzing the content on the basis of key words and comments, these articles are divided into three groups. Some articles are distinguished by their ideas and aims, while others are highlighted by their unique case studies. Inspection of defects, understanding building maintenance and troubleshooting are considered key topics in building maintenance. In general, there are problems in determining the location of building defects, root causes, data and documentation, challenges that often make maintenance management ineffective and cause problems with time and money. The biggest challenge researchers face in building maintenance studies, especially in addressing building deficiencies in different studies, is the need for additional analysis and experimental efforts.

Some of the methods used to identify construction defects are various technologies such as 360° cameras, digital LiDAR and aerial photography, which can be used to improve the monitoring process and the accuracy of the results. However, obtaining sophisticated component information with affordable sensors, investigating different sensor technologies for non-destructive testing (NDT), such as spectroradiometers for defect detection, and improving the intelligent functions of the system to obtain the best algorithms for all conditions are still challenges for researchers and must be continued in the future. Construction defect monitoring is simplified by integrating BIM processes with additional platforms such as Computerized Maintenance Management Systems (CMMS), multi-attribute selection and scanning technologies. The accuracy of this process is further enhanced through the use of higher dimensional BIM technologies such as 6D modeling, which combines data from 3D models, as well as time, cost and carbon footprint analysis. However, in addition to the above program studies, long-term monitoring, load monitoring, watertightness, fatigue, steel corrosion, concrete creep and other environmental factors are also important and should be given greater consideration.

TPM successfully prevents system interruptions during operation and maintenance times. As a result, building managers can take TPM-based measures to avoid interruptions by evaluating the results via an integrated BIM platform. To demonstrate the evolution of building damage monitoring and decision making during the building life cycle, the effectiveness of combining BIM technology with real-time remote sensing tools in the building maintenance process is investigated. Key advances in this area include the consideration of risk measures in building maintenance management and time and energy savings through simulation in building management. Communication and documentation of data or parameters in the building maintenance process and minimizing the environmental impact of building maintenance activities.

As there are no standards for all modeling techniques, researchers have only investigated the use of BIM in surveillance under different assumptions, as there are significant research gaps in all current studies. In addition to how the environment may affect the monitoring of recurring construction hazards and defects, other important gaps include the extension of BIM model data and the management of large data sets. If great importance is not given to monitoring, repairing and preventing defects and damage in public buildings, this has an indirect impact on the aesthetics of the building, user satisfaction, comfort, finances and user safety. Accordingly, a BIM model must be developed for the owner in the operation phase to ensure that the implementation of building maintenance inspection is more effective and the maintenance process runs well.

Acknowledgement
This research was funded by a grant from Ministry of Higher Education of Malaysia (FRGS Grant 9003-00835).

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