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BUILDING INFORMATION MODELING (BIM)-BASED BUILDING CONDITION ASSESSMENT: A SURVEY OF WATER PONDING DEFECT ON A FLAT ROOF

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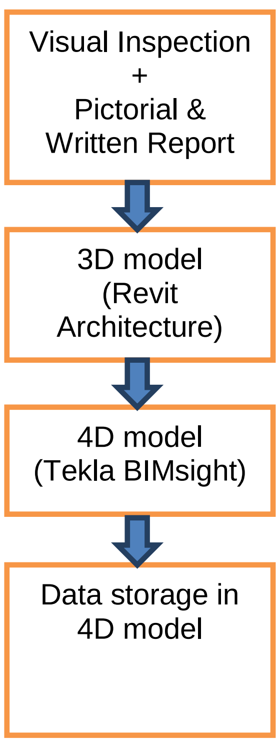
Graphical abstract



Abstract

Building information modeling (BIM) is a technology that should be integrated in the architecture, engineering, and construction industry because of its positive effects. BIM-based building condition assessment (BCA) is an emerging method that should be explored and practiced to obtain the benefits of BIM in building management and maintenance process. The purpose of this paper is to explore the BIM-based condition assessment method by conducting a survey on the water ponding defect on a flat roof. The survey was conducted by a visual inspection and pictorial. A written report was produced after the survey. A 3D BIM model was generated by using Revit Architecture. This model was then integrated with Tekla BIMsight to produce a 4D model that consists of a 3D building view and building information. General building inspection was conducted to determine the existing condition of the flat roof and any possibility of the water ponding defect. Results show that water ponding occurs on flat roof areas during and after heavy rainfall because water does not efficiently flow through the rainwater downpipes (RWDPs). This obstruction in water flow is caused by the presence of dirt and the insufficient number of RWDPs in certain areas. Furthermore, BIM-based BCA shows a positive effect by providing a 4D model that is easy to understand, access, and store by the building management team.

Keywords: BIM, building condition assessment, water ponding, flat roof

Abstrak

Building Information Modelling (BIM) adalah teknologi yang perlu diintegrasikan bersama industri pembinaan disebabkan kelebihannya. Maka, penilaian keadaan bangunan berasaskan BIM adalah kaedah yang perlu diteroka dan diamalkan untuk memperoleh kebaikan BIM dalam proses pengurusan dan penyenggaraan bangunan. Tujuan kertas ini untuk meneroka kaedah penilaian keadaan bangunan berasaskan BIM dengan menjalankan pemeriksaan kecacatan takungan air pada permukaan bumbung rata. Pemeriksaan visual dijalankan dan laporan bertulis serta bergambar dihasilkan. Model 3D dihasilkan menggunakan Revit Architecture manakala model 4D dihasilkan menggunakan Tekla BIMsight. Keputusan menunjukkan takungan air terjadi ketika dan selepas hujan lebat kerana kegagalan air hujan untuk mengalir melalui paip air hujan akibat kewujudan kotoran dan jumlah paip air hujan yang tidak mencukupi. Selain itu, pemeriksaan berasaskan BIM menunjukkan impak positif apabila model 4D mudah difahami, diakses dan disimpan oleh pihak pengurusan bangunan

Kata kunci: BIM, penilaian keadaan bangunan, takungan air, bumbung rata

1.0 INTRODUCTION

Building information modeling (BIM) has been used worldwide in the architecture, engineering, and construction (AEC) industries [1]. BIM is a virtual model that has huge potential for improving collaboration, integration, and communication between related parties in construction projects [2]. This model provides an insight to plan, design, construct, and manage buildings and infrastructures [3, 4]. BIM is also seen as a solution to problems arising from traditional construction issues such as reworks, delays, increasing expenses, lack of communication and coordination, and wastages [5]. The multiple collaborative enterprises in the construction industry are fragmented, thus causing problems in data integration throughout a building lifecycle [6]. Hence, traditional construction methods are faced with problems such as conflicts, complexities, uncertainties, and ambiguities [7]. Thus, BIM implementation aims to eliminate the gap between multiple collaborative enterprises through the use of a virtual model that is loaded with useful information.

BIM implementation should start from the planning stage until the disposal of the building. The longest phase of a building life cycle is the occupancy phase, which starts after the completion of construction until building disposal. During this phase, a building should be managed and maintained properly to ensure the safety and security of the building and maintain the property value. This process is costly [8] and requires work on a regular basis. Therefore, an optimal approach for managing and maintaining buildings at minimal cost should be developed.

Effective building management and maintenance reduces defects in the building through preventive maintenance rather than repair works. The success of building management and maintenance is dependent on accurate building information [9], which can only be obtained through building inspection and assessment. However, traditional building information storage systems using paper-based file systems are complex, difficult to store, and seldom updated throughout the building life cycle. Lin and Su [10] stated that maintenance staff experiences difficulty in preserving facilities when relying on paper-based documents. Thus, the integration of BIM model in building condition assessment (BCA) is the best method to store and update building information for building management and maintenance purposes. This paper discusses the BIM-based BCA for a survey on the water ponding defect of a flat roof.

2.0 LITERATURE REVIEW

Maintenance management is usually ignored by top management until the occurrence of undesirable situations, such as a building disaster [11]. Consequently, poor maintenance will increase building maintenance costs [12]. Reliability and economic factors are often equally important in the selection of an efficient maintenance strategy [13]. Therefore, planned maintenance should be the major activity in a building maintenance [12]. Au-Yong *et al*. [12] suggested that condition-based maintenance is a strategy of planned maintenance to achieve the optimal maintenance expenditure. The success of condition-based planned maintenance is dependent on accurate information about the building condition.

Thus, information from BCA is important for the management team to plan and make appropriate decisions for future maintenance strategies [14]. When information is not easily accessible or is unavailable, the decision-maker cannot rely on scientific data [9] because errors may arise in decision making. Consequently, the implementation of building maintenance will be ineffective and superfluous maintenance may result in large and unnecessary costs strategy [13].

Many design organizations have employed BIM ever since it attracted the attention of the AEC industry [15]. The aim of BIM implementation in the AEC industry is to shift the way of thinking and the working process [16]. According to Akanmu *et al*. [2], BIM is a virtual model that is highly beneficial and provides significant advantages to AEC businesses. Francom and El Asmar [17] indicated that BIM is a process that will significantly improve AEC project performance. Furthermore, BIM is able to connect the virtual model with the physical construction by bidirectional coordination [2]. In an investigation on 106 projects involving the use of BIM in China, Cao *et al*. [18] found that BIM is principally employed as a visualization tool and the implementation is significantly associated with project characteristics.

The involvement of various consultants in construction projects creates problems related to information delivery and sharing. These problems include poor information delivery, inaccurate information transfer, and incorrect information [19]. Haron [20] stated that these problems are the basic things that need to be addressed with effective BIM implementation. The BIM model may create and reuse a consistent digital information model throughout a building lifecycle to overcome the fragmentation issues that exist among construction stakeholders [21]. This approach is adopted because close collaboration between stakeholders is required in developing the BIM model [3].

Mohd Faizal *et al*. [22] listed the following uses of BIM: visualization tool, clash detection, building design, built model, building assembly, construction sequencing, environmental analysis, model-based estimation, facilities management, and direct fabrication. Arayici *et al*. listed the five benefits of BIM: efficient collaboration amongst construction stakeholders; availability of accurate documentation of the building development; common understanding of project costs, schedule, and project progress; ability to assess design alternatives and lifecycle impact; reduced error, rework, and waste for improved sustainability in design and construction [21].

The benefits of BIM implementation in the AEC industry has been recognized by many researchers [2, 23, 24]. However, the potential of BIM in the operation and maintenance phases have not been fully utilized [2]. Thus, the potential of BIM in these phases should be explored, particularly in terms of BCA.

2.1 BIM-based BCA

The key to a successful facility management is accurate building information [10]. Therefore, BCA aims to assess building conditions to provide the required information for building management and maintenance. This approach involves a monitoring process that includes collecting, analyzing, recording, and reporting information [25]. Extensive building data with a manual monitoring process is time consuming [26, 27], and the excessive amount of work required to perform may cause human errors and reduce the quality of manually collected data [25]. Furthermore, paper-based documents hinder the ability of maintenance staff to maintain the building [10]. Thus, a new method should be applied that can facilitate the BCA process, including data storage and updates.

BIM is an ideal tool and platform for developing an inspection and maintenance system [1]. The implementation of BIM to replace a manual monitoring process is considered to overcome emerging problems. BIM can be an effective visual tool for facility maintenance management [10] because it can be designed to provide information quickly about the building and provide a database as a platform for conducting the required analysis and evaluation at all levels, including the operational phase [28]. In addition to visualization, the BIM model also has the ability to analyze and control data that can provide and support FM practice [29]. BIM contains the complete information of a building, which is useful for a facility manager in managing and maintaining the facility efficiently because such information evolves from the planning, design, and construction processes [3].

The main role of BIM throughout a building lifecycle is to provide a visual model and database [30]. The implementation of BIM in facility management can improve data handling processes from the design phase and construction phase to the maintenance phases [2]. The advantage of the combination of computer software with new working practices in BIM is to improve product delivery, which includes quality, reliability, timeliness, and consistency of the process made [16]. At the operational phases, the BIM model can be designed to provide quick information and database for required analysis and evaluation [28]. A good BIM model should contain complete information about a building as it develops through planning, design, and construction; such information can be used by the facility manager to manage and maintain the facility efficiently [3].

Therefore, by using BIM-based BCA, all data from building inspection works can be stored in the BIM 4D model, which consist of a 3D model and information. According to Su *et al*. [31], the implementation of the BIM model can increase efficiency and improve the maintenance information storing system. Furthermore, the maintenance staff can access and review the BIM model for updating related maintenance records in digital format [10]. Finding the location of a defect is easy and quick by referring to the BIM model [31]. Thus, a single BIM model can store information on all design and built asset information [8]. Akanmu *et al*. [2] indicated that the most important benefit of BIM in BCA is that it enables the generation and management of building data during the building lifecycle. Figure 1 shows the concept of BIM-based BCA developed by authors on the basis of literature reviews.

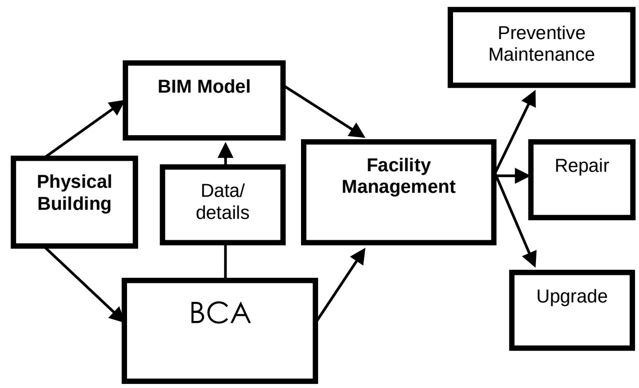


Figure 1 BIM-based BCA concept

As shown in Figure 1, the BIM model should be developed for existing buildings that have been built without the model. The model should be developed on the basis of an as-built building that contains all of the required components. Thereafter, BCA works should be conducted according to the developed BIM model. Data and information from building inspection works should be recorded and stored into the BIM model. Therefore, the facility management team can easily access all building information by using the 4D BIM model, which include the 3D as-built model and related information. This information can be used to plan and execute further maintenance works such as preventive maintenance, repairs, or upgrades depending on building conditions.

3.0 METHODS

The condition survey was conducted on a selected flat roof of a building in UKM Bangi in November 2014. The objective of this survey was to identify the flat roof condition and to identify the possibility of water ponding to occur. The task for the survey was to perform a visual inspection and produce a pictorial and written report. The survey area involved 3 flat roof areas consisting of 15 rainwater downpipe points (RWDPs). This survey was performed by using visual inspection. The overview and existing conditions of the surveyed area has been recorded by using a camera.

The surveyed area was measured with a measuring tape and laser distance meter, and the number of RWDP was recorded. Figure 2 shows the number of RWDP that has been labeled. As an approach to the BIM concept for BCA, a 3D model-based system was generated for this flat roof in Revit Architecture, and the view of the model based on Tekla BIMsight will produce a 4D view of this flat roof. Figure 3 shows a 3D view of the flat roof area generated in Revit Architecture, and Figure 4 shows a 4D view of the flat roof in Tekla BIMsight.

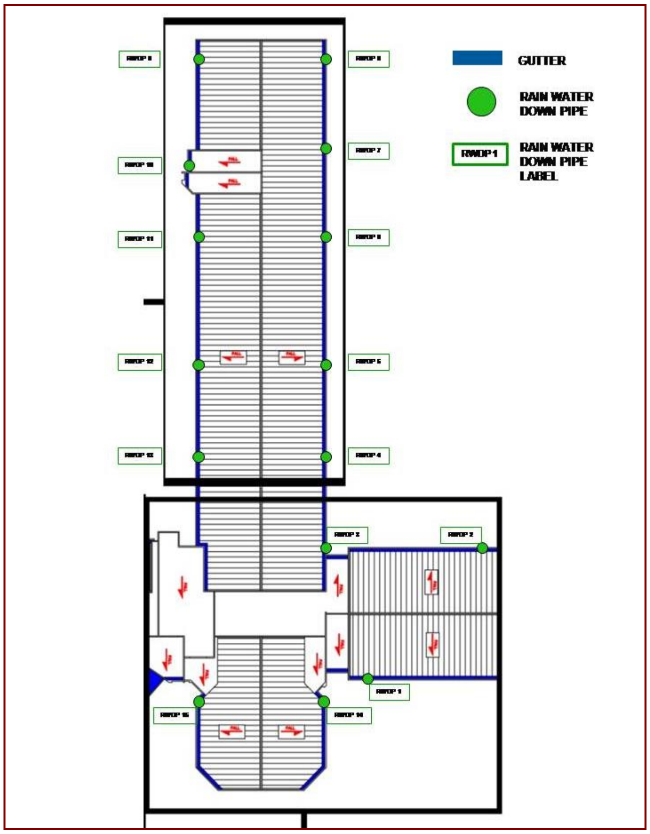


Figure 2 Labelled RWDP

General building inspection was first conducted to determine the existing condition of the flat roof and to identify the possibility of water ponding and watermark on the flat roof surfaces. The inspection also determines the presence of dirt around the location of RWDP that may cause water ponding on the flat roof surfaces. The height of water ponding and dirt are then measured by using a ruler. The finding was summarized according to the criticality of each RWDP, which has a score of low, medium, and high.

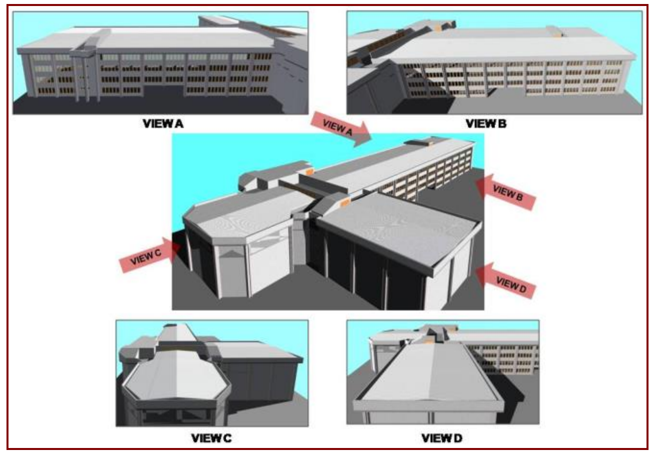


Figure 3 Three-dimensional view generated in Revit Architecture

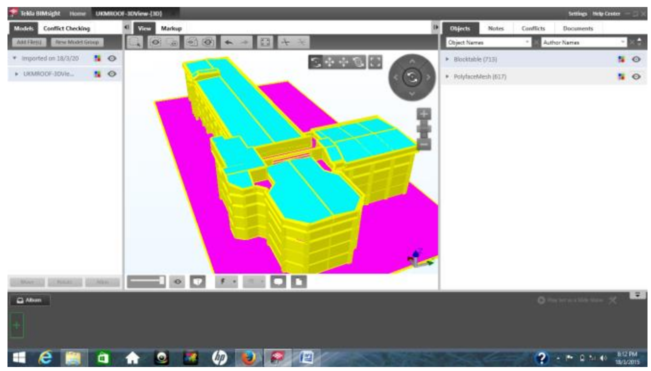


Figure 4 Four-dimensional view generated in Tekla BIMsight

4.0 RESULTS AND DISCUSSION

The survey was conducted on a sunny day. Heavy rainfall has being recorded 12 hours before the survey was conducted. During the visual inspection, water ponding was identified on several areas of the flat roof surface because of heavy rainfall before the inspection.

The first area of the flat roof consists of two rainwater downpipes labeled as RWDP 1 and RWDP 2. No water ponding was observed on the surface area of the flat roof near RWDP 1. Dirt and mold growth was observed on this RWDP and dirt level shows a reading of 10 mm. Water ponding was noticed on the flat roof surface near RWDP 2, and the water level on this area shows a reading between 5 mm to 10 mm height. Dirt and mold growth was observed on RWDP 2, and the dirt level shows a reading between 17 mm to 20 mm.

The second area of flat roof consists of 11 rainwater downpipes that was labeled as RWDP 3 and RWDP 13. No water ponding was observed on the surface area of the flat roof near RWDP 3 to RWDP 11. Dirt and mold growth was observed on RWDP 3, 6, 7, 8, 9, 10, and 11. Dirt levels on RWDP 3 show a reading between 2 mm to 3 mm, and the presence of plant growth was identified near RWDP 3, 4, and 5.

Dirt levels on RWDP 6, 7, 8, and 9 show readings between 3 mm to 5 mm and dirt levels on RWDP 10 and 11 show readings of 10 mm height with the presence of mold growth and plant growth.

Water ponding was identified on the flat roof surface near RWDP 12 and 13. This area shows a water ponding effect because the area was near several outdoor units of air conditioners, and water from the units flow directly into the gutter area. The water level on the RWDP 12 area show a reading of 5 mm, and the water ponding level on RWDP 13 show a reading of 4 mm height. The presence of dirt in this area shows a reading of 10 mm height.

The third area of flat roof consists of two rainwater downpipes labeled as RWDP 14 and RWDP 15. Water ponding was observed on this area because of the water flow from the upper level of the roof. The water level on this area and near RWDP 14 area shows a reading of 4 mm height. Plant growth was also seen on RWDP 15.

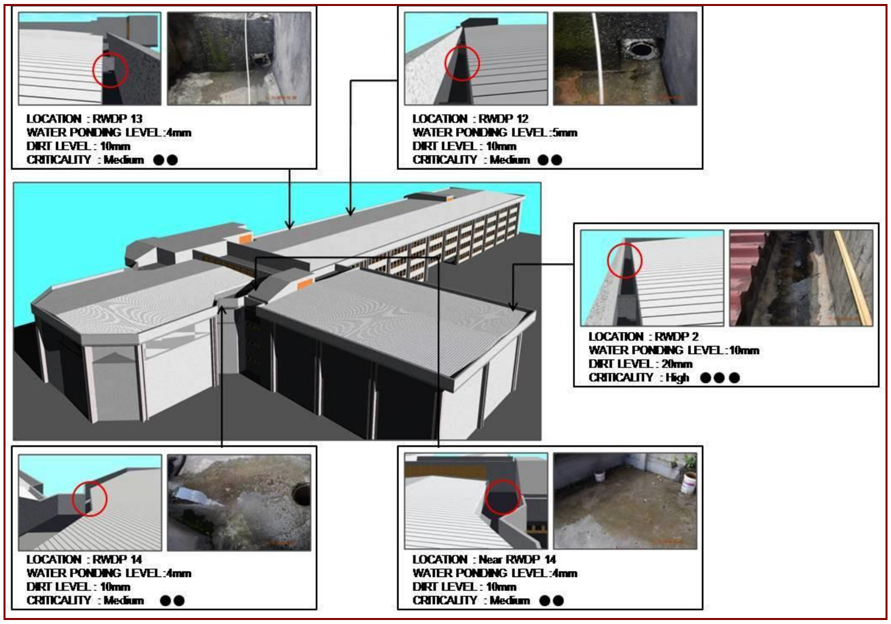


Figure 5 Location of water ponding on the flat roof

Figure 5 shows the location of water ponding on a flat roof by using the BIM-based BCA method. The results of the BIM-based BCA method can be presented by using a model that is integrated with information. The model is the 3D roof image, and the information box contains the defect description, which includes defect location, water ponding level, dirt level, and criticality. This BIM-based BCA result will easily provide quick and valuable information to all levels of various parties to understand the survey results.

Upon observation, water ponding on this flat roof area were caused by the deposited dirt around the RWDP area and the insufficient number of RWDP in certain areas of the flat roof. Rainwater inefficiently flowed through the RWDP because of the presence of dirt and because the flat roof surface is not well directed to the respective RWDP (inefficient flat roof fall). The first and third areas of the roof have an insufficient number of RWDP (only 2 RWDP for each flat roof area).

To determine the most critical RWDP in this flat roof area, Table 1 below shows the criticality level of all RWDP in terms of water ponding, dirt, and height of dirt.

Table 1 Criticality level of RWDP in terms of water ponding, dirt and height of dirt

No.	RWDP	Water ponding near RWDP (Yes or No)	Height of water (mm)	Presence of dirt (Yes or No)	Height of dirt (mm)	Criticality* (Low, Medium, High or Serious)	
1	RWDP 1	No	-	Yes	25	Low	•
2	RWDP 2	Yes	10	Yes	20	High	•••
3	RWDP 3	No	-	Yes	3	Low	•
4	RWDP 4	No	-	No	-	Low	•
5	RWDP 5	No	-	No	-	Low	•
6	RWDP 6	No	-	Yes	5	Low	•
7	RWDP 7	No	-	Yes	5	Low	•
8	RWDP 8	No	-	Yes	3	Low	•
9	RWDP 9	No	-	Yes	3	Low	•
10	RWDP 10	No	-	Yes	10	Low	•
11	RWDP 11	No	-	Yes	10	Low	•
12	RWDP 12	Yes	5	Yes	10	Medium	••
13	RWDP 13	Yes	4	Yes	10	Medium	••
14	RWDP 14	Yes	4	Yes	10	Medium	••
15	RWDP 15	No	-	No	-	Low	•

*Criticality:
Low • : No water ponding, dirt 1–25 mm
Medium •• : No water ponding, dirt 26–35 mm OR Water ponding, water level 1–5 mm, dirt 1–15 mm
High ••• : Water ponding, water level 6–10 mm, dirt 16–25 mm
Serious •••• : Water ponding, water level more than 10 mm, dirt more than 25 mm

5.0 CONCLUSION

The implementation of BIM in the AEC industry was established to improve the quality of process, information sharing, and products. BIM implementation must be continued in the post-construction phases, particularly during the occupancy phase, which is the longest phase of a building life-cycle. Thus, proper building management should be conducted to maintain the building condition and asset value. A building management process relies on the information and data collected by BCA to ensure the effectiveness of maintenance works. Traditional BCA is time consuming, has a manual data transfer, and involves an ineffective information storage system. Therefore, the application of BIM-based BCA is studied to resolve the issue.

The use of BIM-based BCA on a flat roof to detect water ponding shows a positive effect. Survey results can be presented by using a 3D model integrated with information. This type of information is simple to understand and can be used as a reference for other processes. Furthermore, all of this information can be stored in a single model. Future building management teams will be able to access the whole building history to plan and execute proper building maintenance works.

The result of this survey shows that water ponding occurred on this flat roof area after heavy rainfall. The presence of water ponding shows that water does not efficiently flow through the RWDP during heavy rainfall and caused water ponding on the flat roof surface. This survey also identified the presence of dirt around the RWDP and the insufficient number of RWDP in certain area of the flat roof. These factors prevented the efficient discharge of water from the roof surface. Out of 15 RWDP, 3 RWDPs have a score of medium criticality, namely, RWDP 12, 13, and 14. One RWDP has high criticality: RWDP 2. Therefore, the regular cleaning of the area near RWDPs and the installation of new RWDPs in critical areas can mitigate this shortfall. To monitor this process in real time, sensor technology is one of the best approaches because it can detect a problem in real time even during rainfall. Water ponding defects should be prevented because it will lead to another serious defects in the flat roof and will eventually weaken the flat roof structure.

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