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Evaluation of practicality of virtual design and construction (VDC) with 5D building information modelling (BIM) through a case study

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Abstract. Virtual design and construction (VDC) is defined as the use of multi-disciplinary performance models for the purposes of design-construction projects. The use of VDC in construction projects enables the stakeholders to communicate and visualize the buildability and construction sequence which will impact on a project's success in terms of delivery time and cost. This case study investigated the process of integrating different dimensions of information such as time scheduling (4D) and cost estimation (5D) with a 3D model to simulate a 5D Building Information Modelling (BIM) process. The study explored the application of VDC with 5D BIM for a commercial building, namely Universiti Tunku Abdul Rahman (UTAR) Sungai Long City Campus. Through this case study, it enables comparisons of a virtual model and an actual construction in order to evaluate the advantages, practicality, and limitations of the VDC applications. The 5D model provided comprehensive information to manage the complex design-construction process by considering its timeline and cost. Six modelling stages were undertaken, namely inputting and modelling, clash detection test, time scheduling, quantification and cost estimation, virtualization, and walkthrough of the model. The results revealed that the practicability of the 5D BIM was influenced by the modelling effort, inter-operability, information output and limitations. The study also showed that VDC with 5D BIM significantly reduced the technical barrier for clients to participate in construction project, thus increasing the clients' satisfaction of the works by bridging the gap of perception and actual outcomes from the construction.

1. Introduction

Construction processes have evolved with the implementation of Virtual Design and Construction (VDC) in visualizing the 3D environment of the building. In recent years, a growing number of researchers focused on the study of the benefits, limitations and practicality of VDC in design-construction projects [1-5]. By adopting BIM technology (i.e., subset of VDC), an enhancement of the construction planning emerged from two dimensional (2D) drawing [6] to the integration of modern digital technologies with various dimensions of useful information (i.e. 3D, 4D, 5D) [7]. This systematic integrated digital information could then be communicated through VDC (i.e., visualisation) for an effective communication between the stakeholders during the project design phase.

In construction industry, the applications of BIM can be classified into preconstruction, construction and post-construction phases. Four dimensional (4D) modelling enables the users to visualize construction activities and to identify time and space constraints with the aids of relevant computing tools [4]. Based on technological sequence of scheduling the tasks of a project according to the specified technical requirements [8] and resources [9], the time management of an entire construction project can be derived [10]. Construction plans can be represented graphically by adding a layer of the time dimension to the 3D model to allow project planners to simulate and analyze any unpredicted scenarios before commencing work execution on site [11]. With the advantages of building systems analysis (e.g. clash detections test) [12] and time planning scheduling [5], stakeholders are able to track the progress of various parties working on the same project and make a better decision based on their expertise. With the supporting materials of photo-realistic representation that can be generated through VDC, it also improves collaborations among the stakeholders [13].

Recent advancement in building information modelling has seen the incorporation of the n-Dimensional (nD) information in building-construction, i.e. cost estimation. This includes the fifth Dimensional (5D) modelling that is made possible after generating the quantity takeoff for the construction components. The use of 5D modelling enables tracking of cost expenses [9] and quality level affected [14] in a construction project. This study aims to explore the applications of VDC with 5D BIM for a commercial building. Through the VDC with 5D BIM, their contributions to better project time and cost management during the construction phase are evaluated. The application of VDC could also benefit the facility management during the operation phase as the facilities and utilities which have been modelled can be tracked and monitored for maintenance purposes.

2. Methodology

This paper aims to study the visualisation of a design and construction process of a commercial building using Autodesk Revit 2016 and Autodesk Naviswork Manage. The sample project used is the building of Universiti Tunku Abdul Rahman (UTAR) Sungai Long City Campus, a building located on a commercial land title completed in 2015. The building stood 11 stories tall with 2 levels of basement. In order to enhance the effectiveness of the building information model, clash detection test, quantification of components, time scheduling for construction components, and case study of walkthrough the completed virtual building are demonstrated in this study.

2.1. Collecting, inputting and managing of building information from 2D plan

Completing the 3D building information model is the very first step to enhance the quality of a construction project by enabling a better coordination of site planning, activity sequencing, site organization, site management and clash detection test with other professional works. Thus, analysis of the building information from the 2D plan and identifying their significance levels are essential before they can be input into the 3D model. BIM promotes the representation of a building design in a 3D model incorporating geospatial data, graphical, and non-graphical data provided by any involved practitioner to allow manipulation of its database. After all the data have been analysed, the information was ready to be imported into Autodesk Revit by incorporating other disciplines e.g. civil and structural engineering and interior design. Figure 1 shows the components that were input and managed in a proper coordination with the aids of grid lines from the 2D plan.

Figure 1. Structural and architectural components for the case study.

2.2. Clash detection between information models

Clash detection test enables users to identify and manage the potential impact before construction phase begins. Besides, it proves a better coordination between the construction participants.

2.3. Quantification of information components for cost estimation

Quantification of information components is also known as quantity takeoff, enabling the users to estimate the cost, volume of concrete casting, area and number of units for specific components. Quantity surveyor or cost engineers will have an advantage of performing the quantity takeoff for the materials with better accuracy and faster results. Figures 2 and 3 show the quantification of the components performed by Autodesk Revit and Autodesk Naviswork Manage, respectively.

Figure 2. Quantity takeoff result from Autodesk Revit.

Figure 3. Quantity takeoff result from Autodesk Naviswork Manage.

2.4. Scheduling information progress

Time scheduling was performed to estimate the cost with animation features after quantification of information components. It showed a reference to match up with construction process during the

planning phase of a construction project. Figure 4 shows the inputs of time scheduling with estimated cost into the time-liner function.
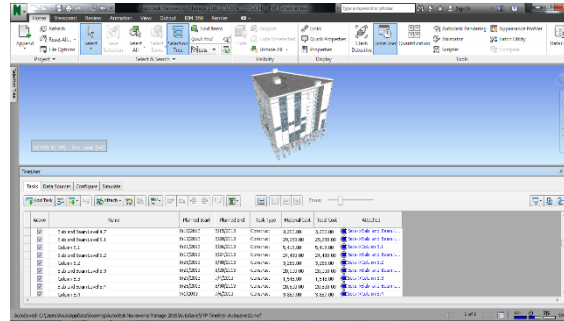

Figure 4. Inserting time and cost for information components in Naviswork Manage.

2.5. Virtualization of building information model
Animation of construction progress will be created concurrently with the input of time scheduling from the previous stage. By using the animation, it enabled the presentation of 5D Building Information Model for the needs of construction participants. Besides, for the actual construction progress, 5D BIM as-built information virtualisation can be carried out to monitor between the actual progress and the planned progress.

2.6. Third-Person walkthrough for virtual building
The final stage involved a third-person walkthrough in a virtual building. In order to further enhance and inspect the quality of a model at a closer view, the walkthrough viewpoint was generated to help clients to preview and link to his perspective since it is similar as a real person walk around the project site.

3. Results and Discussions
Figures 5a and 5b show the completed virtual building model and the actual constructed building, respectively. Apparently, the virtual model showed a close representation of the actual building. Clash detection, quantification, time scheduling, and building walkthrough were performed based on the virtual model.
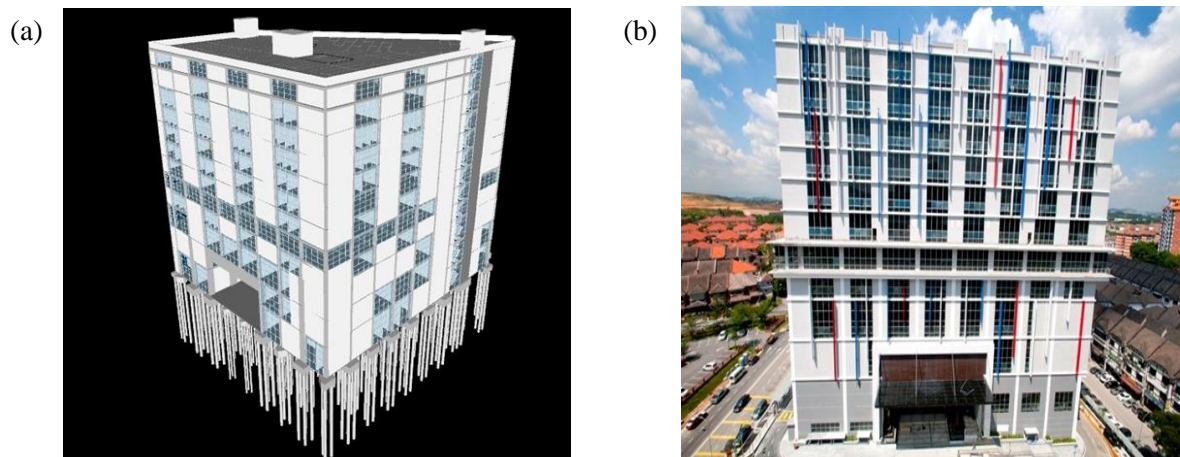

Figure 5. (a) 3-dimensional view of the virtual model, (b) Actual completed building.

3.1. Clash detection reports

Corrective measures were essential for resolving clashes of the models created. Clash report with figures and descriptions could be generated into HTML file or txt file. By performing this test, it reduced the possibility of clashes between different building components, and hence reduced the cost and time for a construction.

3.2. Quantification by Autodesk Revit and Autodesk Naviswork Manage

Quantification was performed by both Autodesk Revit and Autodesk Naviswork Manage. In Autodesk Revit, components that were taken off from the model can be clearly shown in terms of location and coordination. However, in Autodesk Naviswork Manage, it automated and separated the takeoff components into complex information while more information was presented in the model.

For residential buildings or relatively small-scaled buildings, quantity takeoff performed by Autodesk Naviswork Manage could be a preferred choice as it enables presentation of detailed results due to the lesser amount of building information compared to commercial or high rise buildings. As for the commercial building in the present case study, the quantification by Autodesk Revit is a recommended choice. Quantity takeoff in Autodesk Revit provides multiple options in taking off the building information, allowing multiple category scheduling such as analytical space, casework, ceiling and etc. Quantification of Autodesk Naviswork Manage was automatically categorized into different categories once the Revit file was appended into Naviswork Manage. For example, the components in Autodesk Revit such as brickwalls and interior partition wall were defined as "Basic Wall" type in Autodesk Naviswork manage.

Autodesk Revit enables user to choose the available parameters, or add users' own parameters or even customize a parameter's formula to present the data and values of current models. However, Autodesk Naviswork Manage does not provide flexibility to choose, decide or edit the parameters for the quantity takeoff because it has fixed the parameters such as length, width, thickness, height, perimeter, area, volume, weight, count and primary quantity. However, users can edit the formula for the variables mentioned above and also edit the SI units for the variables. Besides, cost estimation only can be performed when the quantification workbook was exported to a spreadsheet file.

3.3. Time scheduling integrated with cost estimation

By virtualising the construction progress of a building information model, construction participants are able to save cost by arranging the equipment and material for their own professional works such as scaffoldings, shipping of material, installation of service and etc. They are able to "preview" the progress of the construction work before it begins. In Naviswork Manage, it enables the input of costs for labour, machinery, and subcontractors. However, the present study only attempted on the analysis of material costs.

3.4. Advantages of walkthrough a virtual building

Some clients may have difficulties to imagine the interior views of the proposed buildings due to limited knowledge and experiences in building design and construction. By providing a walkthrough viewpoint for clients, it further ensures that the proposed design is meeting the clients' requirement and intention. In addition, the quality of the building construction can be improved owing to the better visualization of proposed building even before the construction progress begins. Figures 6 and 7 show samples of walkthrough views between the completed building and the virtual building.
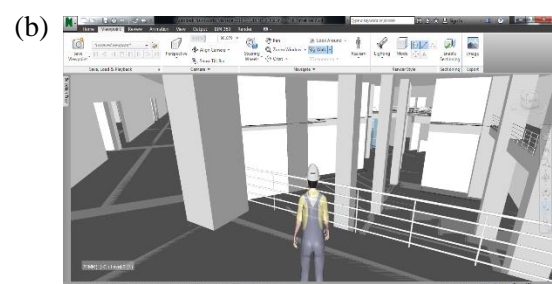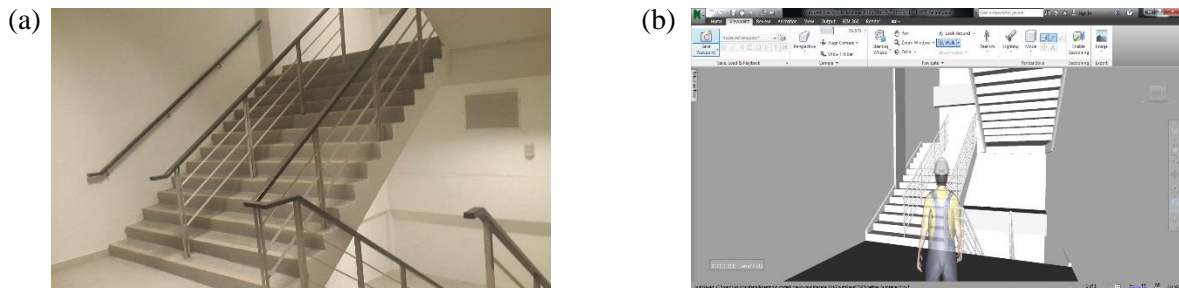
(a)   (b)

Figure 6. Viewpoints 1 of (a) Actual completed building, (b) Virtual building.

Figure 7. Viewpoints 2 of (a) Actual completed building, (b) Virtual building.

4. Practicality of 5D BIM

Based on the present case study, the practicality of the 5D BIM modelling were evaluated by the authors based on the experiences of conducting the BIM modelling. Qualitative ratings ranging from "poor" to "neutral" and "good" were given to each of the processes involved. From the first stage, it was found that the effort of modelling was highly dependent on a user's skill level. This is similar to CAD, and hence it was considered "neutral". Inter-operability was considered "poor" because different modelling tools are based on unique system and engine that are competing against one another. The information output was very comprehensive and thus it was considered as "good" when compared to 2D plan. For stakeholders who lacked of knowledge in BIM, it may deter the stakeholders to proceed to subsequent stages.

In terms of inputting the information for cost estimation, the effort was rated "good" since the process was considerably simpler compared to manual taking off. The inter-operability was considered as "neutral" as compared with other more advanced software that are normally used by quantity surveyors. However the output information was very fast and accurate. The limitation for this stage showed that suppliers cannot update the information for costing automatically.

With regards to simulated time scheduling in 3D model, the modelling effort was considered as "neutral". Unlike the first stage, collaboration that involved completed building information model was "easy" due to high inter-operability. The information output was "good" as non-professional stakeholders were empowered to easily understand 5D BIM. However, when it comes to the planning for the construction, it needed site knowledge and experience to analyse the quality of the results.

In the process of virtualisation, the effort highly depends on existing 5D BIM quality. It was determined as "neutral" in this study. However, the advancement of technology certainly will reduce the modelling effort. Both inter-operability and information output were "good" due to the direct link to the perspective of clients or end users.

5. Conclusion

The present case study shows the potential of VDC with BIM leading to a more efficient process in construction industry. Even though it is possible to integrate up more than five dimensions of information, excessive information may trigger the complexity and impede the VDC implementation process. On one hand, the integration of VDC and 5D BIM promotes the efficiency and accuracy of construction planning process. On the other hand, it also enhances construction industry stakeholders' decision making abilities which are conventionally constrained by the limitation of 2D CAD workflow. Moreover, VDC with 5D BIM significantly reduces the technical barrier for clients to participate in construction project, thus increasing the clients' satisfaction of the works by bridging the gap of perception and actual project outcomes.

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