Virtual design and construction (VDC) for double-storey residential building – Case study

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Abstract. Virtual design and construction (VDC) is a combination of building information modelling (BIM) technologies with adequate work and management scheme for product in supporting people working together in an integrated and simultaneous way. The use of VDC in construction project has positive effects in reducing risk related to design and multidisciplinary coordination. This enhanced the decision-making process by reducing miscommunication issue. This paper presents a case study to investigate the process of integrating different dimensions of information i.e., time (4D) and cost (5D) with a 3D model for double-storey residential building construction considering the zoning conditions. Implementation of VDC with zoning plan leads to an efficient construction management in project feasibility study. It enabled comparison of a virtual model to evaluate the advantages and practicality of VDC for double-storey residential building. The 3D architectural and structural models elements are prepared at level of detail (LOD300) using Autodesk Revit. The 3D models are then integrated to simulation software (i.e., Autodesk Navisworks Manage). Visualisation of the project (i.e., 4D and 5D) is achieved as the outcome of the simulation by implementation of VDC. The results revealed that the practicability of VDC was affected by LOD and software interoperability.

1 Introduction

Virtual Design and Construction (VDC) method is defined as the use of integrated multi-disciplinary performance models of design-construction projects to support explicit and public business objectives [1,2]. It should be distinguished between VDC with Building Information Modelling (BIM). BIM is the virtual model which displays the physical reality, however, VDC is the process to model the construction project by using BIM, organisational, process modelling tools and collaborative techniques [2,3]. It has brought several advantages to the architecture, engineering, and construction (AEC) industry including visualisation, integration for better communication and prevent rework and automation during the project design phase [3,4]

Prior to VDC, paper-based documentation i.e., 3D BIM output and 2D design are adopted in AEC industries. Although the BIM system has been used in the design-construction process, the process is rather rigid and incomprehensive without integration of

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software product, analysis, and organization [5,6]. The BIM has successfully evolved the method of construction design, analysis, and management with its technology enhancement. The introduction of 4D time scheduling and 5D costing process visualization is one of the important features in VDC that added value in construction project [6,7,8]. The 4D and 5D models enhanced communication and interaction among stakeholders. This study aims to explore the applications of VDC with 5D BIM for a double-storey residential building. Through the VDC with 5D BIM, the contribution to time and cost management during pre-construction phased are evaluated. The application of VDC could benefit the stakeholders in feasibility stage as the construction modelling and simulation can be evaluated prior to actual construction for more effective project planning and management processes.

2 Methodology

This paper aims to study the VDC process of a double-storey residential building by considering the zoning effect using Autodesk products. The proposed methodology of the research is shown in Figure 1. The research methodology is categorised into two stages i.e., (i) modelling and design, and (ii) time (4D) and cost (5D) simulation.

![Fig. 1. Proposed methodology of the research.](image)

In stage one, the architectural and structural models are developed based on a constructed double-storey residential project in Malaysia. Upon completing the 3D architectural model, clash detection is performed with other professional works (i.e., structural framing) to enhance the quality of the model. The structure model is then created to determine the locations of columns and beams to be evaluated using Autodesk Robot Structural Professional Analysis and Midas Gen. The information (i.e., material, properties, colour and manufacturers’ information) of the structural elements are incorporated into the models by achieving the model elements at LOD 300. Schedule of the model elements is prepared to list the information of each model element created in the models.

In stage two, the 3D architectural and structural models are integrated with Autodesk Navisworks Manage. The work breakdown structure (WBS) incorporating project schedule and costing are prepared in Microsoft Project with the quantity take off obtained from the 3D models. The project schedule is estimated by the duration and predecessors of the construction activities, while the project costing is estimated via the schedule obtained in modelling process in Stage 1. The project schedule and costing information is then
imported into the integrated model to perform 5D simulation. The construction process is simulated is performed in 5D environment to visualise the virtual construction process.

3 Result and discussions

3.1 Zoning plan

To implement zoning plan, the site layout is proposed by interpreting the WBS of the site plan as shown in Figures 2 and 3. The zoning plan is proposed based on the desired size, number, and sequencing of zones. These are affected by the number of labours expected at one time and the number of houses in a zone during construction. In this study, grouping in block is preferred compared to grouping in row by considering the equipment mobility. The segments of the zones are divided based on the site plan where there are seven to ten houses in a zone, and three to five houses in a sub zone. A total of nine zones is considered for a total of seventy units while two sub-zones are divided in a main zone as illustrated in Figure 3. The zones with important facilities located are be assigned at the final of the sequencing chain.

Through zoning plan, the management of the construction project can be facilitated in zones via VDC. The houses in the same zone possess the same commencement and completion dates. The construction work commenced from zone 1 to zone 9 following the construction work types as shown in Figure 4.

The implementation of zoning plan in VDC process results in higher accuracy of simulation result of the virtual construction process. The work sequencing considered during the design stage contributes lesser conflict and more coordinated work on site. Through virtual construction, the uncoordinated arrangement can be revised to visualise the final output during planning stage.
3.2 Model Development

3.2.1 Architecture and structural modelling (3D)

The double-storey residential building consisted of average land size of 50’ × 80’. The information of the model elements was incorporated to LOD300. The expected appearance and the quality of work for whole project can be visualised in detail by viewing into the integrated model as shown in Figure 5. The integrated model provides the visualised image of the design outcome which is needed by the project stakeholders (e.g., client, architect, and property buyers) to prompt decision making on the design change.

![Fig. 5. 3D models integration.](image-url)
3.2.2 Time and Cost Modelling (4D and 5D)

The quantification was performed by both Autodesk Revit and Autodesk Naviswork Manage. Task activities for the components are determined and categorised. Taking the WBS construction of wall as an example which started with brick laying, plastering, skim coat and lastly paint. The definition of task activities can be visualised via the integrated model. With 3D model visualisation, the duration for each activity can be easily estimated start from brick laying activities to installation of electrical fixtures. The 3D model enables visualisation of task activities, duration, and predecessors instead of imagination as shown in Figure 6.

The tracking of construction progress is easier in using Autodesk Navisworks Manage with project schedule. Figure 7 shows the progress of each milestone accomplished in the timeline of Autodesk Navisworks Manage. From the WBS timeline, the progress of structural work at Day 56 is 17.2 % while the progress of architectural work at Day 56 is 4.46 %. It is useful to track the progress of a zone or even to check whether an activity has started at the planned scheduled.

![Fig. 6. Work breakdown activities integrated with 3D models.](image)

![Fig. 7. 5D simulation of the project.](image)

Besides, the cost needed within a period can be examined and visualised in 5D simulation. The expenditure in the period of Days 31 and 76 (45 days) as shown in Figure 8 are considered. From the WBS timeline, the structural work of the project at Days 76 and 228 reached 23.55% and 71.83% respectively. The cost spent within this period is RM
2,397,245.56 by obtaining the difference of total cost spent at these two different timing. Cash flow can be managed in advance at Day 31 to be prepared for the cost in future forty-five days.

![Day 31 Costing Evaluation](image1)

![Day 76 Costing Evaluation](image2)

Fig. 8. Costing evaluation via 5D Simulation.

VDC in construction project promote better decision making and progress tracking with time and cost evaluation. It enables the stakeholders to visualise the actual conditions of the project prior to the actual construction. It also prevents rework and/or work change in the future which in turn result in time and cost saving.

### 3.3 Interoperability of VDC tools

The interoperability of the VDC tools used in this study are investigated through the data transfer and the communication among the models. The interoperability among six software used in the research are investigated as shown in Figure 9.

![Interoperability Diagram](image3)

Fig. 9. Interoperability of VDC software used in the research.
For data transfer, there are different levels of satisfaction obtained based on the type of software used. The models developed with the same software developer performed well in terms of data transfer e.g., the interoperability between both Autodesk Revit and Autodesk Navisworks Manage. The information transferred from Autodesk Revit to Autodesk Navisworks Manage is successful except the information loss of internal layers of wall. The information transfer from Autodesk Revit to Midas Gen (i.e., different software developer) generated significant amount of information loss such as the boundary support and storey height. The transfer of information is carried out by generating the Autodesk Revit model information into text file before export to Midas Gen. It results in information losses due to the conversion of information format. The input of Microsoft Project requires user manual input instead of transferred from the other software. The transfer of information from Microsoft Project to Autodesk Navisworks Manage is satisfactory except the intolerant to update.

It can be observed that the software under the same developer show better interoperability such as Autodesk AutoCAD, Autodesk Revit, Autodesk Robot Structural Analysis Professional and Autodesk Navisworks Manage. It is because the interoperability between the software is considered as the factor during research and development stage of the software. Unlike Midas Gen and Microsoft Project, add-ins for interoperability are not developed at the early stage of software development hence there is inconvenience or information loss during the information transfer.

In summary, the interoperability of the software improves the efficiency of coordination work. The convenience of information transfer expedites the management work as the changes of the planning can be updated faster than contemporary approach. Rework can be reduced and prevented with the automation process brought by VDC.

4 Conclusions

VDC is an innovative approach in managing construction project. In this study, VDC implementation is carried out by considering the zoning effect in a construction project. Zoning plan promotes more accurate simulation results as it considered the external factors that affect the work coordination to improve the construction workflow. The practicability of VDC depends on the interoperability of VDC software. It is excited to identify that the interoperability of software reduces a lot of manual work to transfer the information. Besides, more automated work can be expected by using software to accomplish the tasks. In this project, the interoperability of software selected is satisfactory and the efficiency of project management is guaranteed. Although the transfer of information throughout the VDC process is yet to be fully automated, the efficiency of work is still higher than adopting contemporary project management. More automated work process and data transfer are expected to expedite the work.

References