Five-dimensional Simulation of Bridge Engineering Based on BIM and VR

K. C. Wang[a], S. H. Tung[a], W. C. Chen[a], and Z. C. Zhao[a]

[a]Department of Construction Engineering, Chaoyang University of Technology, Taiwan
E-mail: wkc@cyut.edu.tw, s10811614@gm.cyut.edu.tw, xxx56618@gmail.com, g90253@gmail.com

Abstract –

Building information modeling (BIM) is a rapidly developing technology used in the construction industry. Many construction companies have implemented BIM into their construction processes for executing various construction management tasks, including four-dimensional (4D) progress simulation and cost control. However, 4D progress simulation has not been simultaneously integrated and compared with cost control thus far. With the execution of this simultaneous task, the relationship among project progress, construction cost, and project components can be explored. Moreover, currently, when conducting a cost review, discretionary adjustments cannot be performed based on an actual site implementation. To this end, in this study, first, the quantities of each of the cost items are calculated using BIM and are matched with the corresponding construction progress. The quantities of each of the cost items can, therefore, be included in each construction progress report. Next, BIM is integrated with the construction cost and the project schedule to generate an S curve concurrently with the 4D simulation. By using the S curve, cost control can be performed according to construction progress. In addition, the proposed model can be presented clearly by using virtual reality (VR).

Finally, this study explore the feasibility of the proposed model by applying it to a bridge construction project. The results indicate that the cost of each stage can be clearly determined using the proposed model. When a cost item is unclear, it can be compared with the simulated construction progress. Coordination and management can be performed, and any gaps therein can be filled early to increase the efficiency of the management process.

Keywords –

Building Information modeling; Virtual Reality; Five-dimensional Simulation

1 Introduction

Building information modeling (BIM) is a rapidly advancing technology in the construction industry. Numerous manufacturers use BIM to manage operations during construction, such as four-dimensional (4D)[1,2] progress simulations and cost control. Progress schedules are linked with BIM components by using 4D progress simulations. Accordingly, BIM models are progressively developed according to the progress schedules, which enable examinations of crucial matters and management items during each operation. Cost estimation entails quantity calculations using BIM models, which link the unit price of each work item and distribute the cost of items to corresponding operations[3]. This allows users to determine the daily costs incurred from various operations and plot a cumulative cost curve (S-curve) [4].

Despite the prevalent use of 4D progress simulations and cost control in construction companies, they have yet to be integrated together to simultaneously determine the relationships between progress, costs, and building components. Thus, when conducting cost reviews, construction companies cannot account for actual situations at the construction site or make adjustments accordingly. Therefore, this study integrated each cost item and its corresponding BIM model into 4D simulation task lists and integrated construction costs and schedules to generate S-curves. This enabled real-time simulation of construction progress by using the models and control costs by using S-curves. In addition, virtual reality (VR) was used to clearly present the models.

2 Literature Review

2.1 BIM 4D Progress Simulations

Generally, 4D simulations are effective auxiliary tools for construction planning and monitoring and help convey construction-related information. Early detection of conflicting construction items and process problems can help construction companies save considerable

money. Communication during meetings can help clarify problems, discuss issues related to construction interfaces, facilitate the attribution of responsibility, save communication time, and reduce wasted time resulting from misunderstandings. 4D simulations offer visual information to no construction personnel, and BIM provide easy-to-understand information that allows them to solve problems during preconstruction, diminish construction risks, control progress, and plan and review the planning of building interfaces and circulation. By using 4D simulation visual technology, construction companies can quickly understand relevant situations, which allows them to save communication time, reduce construction errors, enhance efficiency, and lower costs [5].

2.2 BIM-based Five-Dimensional Cost Control

Replacing traditional two-dimensional (2D) design processes with those that involved the integration and visualization of three-dimensional (3D) parameters and objects substantially reduces the number of drawings used. Moreover, this reduces the amount of work overseen by entry-level staff, which effectively integrates human resources and streamlines manpower costs. Construction schedules and costs are closely related, and 4D schedule planning enables managers to accurately monitor construction quality and progress, thereby controlling construction costs. Although effective in many respects, traditional 2D drawings are ineffective in presenting the number and areas of 3D space in houses. Five-dimensional (5D) cost estimates can be employed to perform detailed estimation of areas and material costs by using drawings. Specifically, this approach considers construction companies' budgets and material unit prices, accurately estimates construction costs, and reduces material estimation costs [6].

2.3 BIM and VR Integration

Intrgrating BIM and VR is a revolutionary breakthrough in the construction industry. BIM enhances authenticity, motion capture precision with VR plugins, and display resolution. BIM+VR has been promoted in the construction and construction marketing fields and enable the integration of BIM and VR systems. Such system integration prevalently used in the construction design industry. Promoting BIM+VR is possible because of advances in computer and Internet technology, which offer the construction industry enhanced computing power and effective software–hardware connections. Applying a BIM+VR system in construction projects and construction marketing is the result of increased investments in relevant systems by the construction

industry and the public's improved consumption power [7].

3   5D   Simulation   of   BIM+VR-Based Bridge Construction

3.1   BIM Model Building

This study entered various building dimensions from 2D drawings into Revit to generate 3D models. In general, each building component is separated during the drawing process to allow users to click on the building components separately during component scheduling (i.e., when selecting components and their corresponding operations) and design (Figure 1).
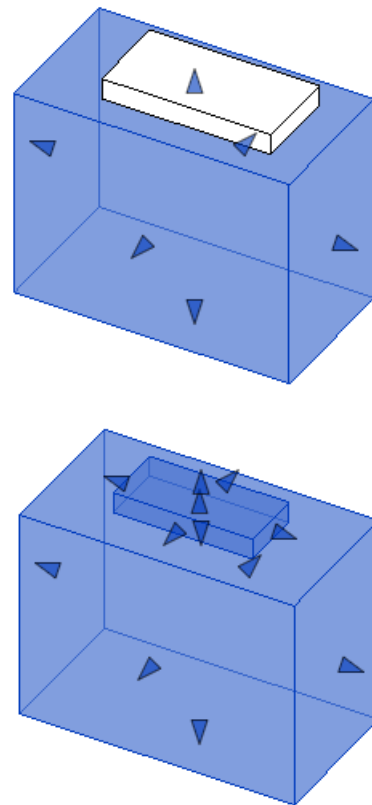

Figure 1. Difference between models with and without separated components

3.2   Number of Various Components and Cost Calculations

The concrete cost is determined by calculating the concrete required using the BIM model and multiplying

this number by the concrete unit price. The template cost is determined by calculating the surface area (using the BIM model) and multiplying this number by the concrete formwork unit price.

Because rebars are not drawn when building the models, the rebar cost is determined by calculating their lengths by using the rebar distribution diagram, multiplying these numbers by their corresponding unit weights, and multiplying the total weight by the unit price. The same calculation method are employed to determine the costs of other materials.

3.3 BIM Models Integrated with Construction Schedules: 4D Simulations

In this study, work items that needed to be completed in the progress schedule network diagram were first identified because numerous work items were completed prior to actual construction. Because this study only investigated the actual construction, work items that were completed before and after the construction process were removed. According to the progress schedules, work items and their corresponding components were integrated into a task list to adjust parameters such as construction time, animation speeds, animation effects, and illumination level to ensure that the 4D simulations ran smoothly.

3.4 3.4. Costs Integrated with 4D Simulations: 5D Simulations

The cost of each component previously calculated is entered into each progress schedule item. This allows users to know the total work item costs when performing 4D simulations. The users learn of these costs by selecting the construction shapes desired and examining the cost curves generated. The construction schedule–cost integration process is described as follows:
(1) The construction schedules and costs are integrated into an Excel sheet.
(2) The costs are entered as the material costs in actual construction schedules.
(3) The construction shapes in the left column of the 4D simulations are selected to generate cost curves.

3.5 VR and 5D Cost Control Integration

For managers to oversee the construction of a building as if they have participated in the construction process in person and review the construction progress, this study displayed the 5D simulation results in VR environments. By using the VR function of Fuzor along with external hardware devices, handles, and a VR head-mounted display, users can observe 4D VR simulation models to simulate authentic construction processes.

External drive equipment that connects the built-in VR functions of Fuzor with external VR drivers (e.g., STEAMVR.GeForce) include Sony PlayStation, Sony VR, and HTC Vive head-mounted displays. Users who do not have this equipment at their disposal could have used a smartphone with easily accessible VR glasses to enjoy the VR experience.

4 Case Study

4.1 Case Describing

This study use a cable-stayed bridge as a case project. The cable-stayed bridge investigated is near the National Freeway 1 Daya Interchange, spanned Provincial Highway 74, and connected to Shuinan Economic and Trade Park in Taiwan. The sketchup model of case project is shown in Figure 2.

Figure 2. The sketchup model of case project

4.2 BIM Model Construction

The bridge was drawn in four stages: the drawing of the pier foundation, bridge roads, main tower, and steel cables. When drawing the bridge, the Revit group was turned on, and the computer-aided design drawings of each component were imported. Subsequently, the extrusion function was used to draw the bridge according to the construction shapes desired and elevations set. All components had to be drawn separately when drawing the bridge.

The bridge roads drawn were divided into six segments, and the components were drawn using the cross-sections of the roads. Because the bridge was not straight but curved, this study developed bridge roads through the sweeping method in Revit.

The main tower comprised 14 steel components that were drawn separately before being put together. The left and right sides each had seven components,. Similar to the bridge roads, the components were developed using the sweeping method. The main tower model is shown in Figure 3.
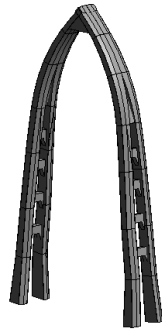
Figure 3. The BIM model of the main tower

Steel cables were found on all four sides of the bridge. Each side of the bridge contained 24 steel cables for a total of 96 steel cables. The steel cables were drawn using built-in components of Revit. Because some road surfaces were tilted or had turns and because steel cables in different sections varied in length, the cables on the four sides were drawn individually, and the cable lengths and locations had to be adjusted. Finally, the pier foundation, bridge roads, main tower, and steel cables were integrated, as presented in Figure 4.
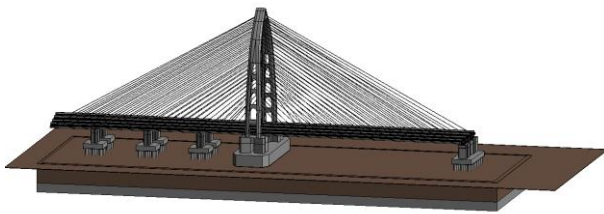

Figure 4. The BIM model of the integrated model

4.3 Number of Each Component and Cost Calculations

The bridge was built using steel and reinforced concrete, and the upper and lower parts were constructed using steel and reinforced concrete, respectively. Calculations revealed that the quantities of concrete, rebars, concrete formwork, road steel plates, and main tower steel plates used were 15,722.3 m^3, 2,081,987.6 kg, 3,882.2 m^2, 844,062.3 kg, and 945,862.2 kg, respectively.

Revit was used to calculate the volume of the building components, from which the quantity could be determined. The components calculated included full-casing foundation piles, foundations (e.g., precast and self-filling concrete), piers, top beams, steel roads, parapets, asphalt concrete, the steel main tower, and the concrete formwork.

4.4 Costs of Performing Calculations Through BIM

After obtaining the quantity of each component by using these calculations, this study searched for the unit price of each component by using the unit price database prepared by the Public Construction Commission. The two variables were multiplied to derive the costs. The costs of concrete, rebars, the concrete formwork, road steel plates, and the main tower steel plates were NT$33,803,035, NT$41,639,753, NT$1,071,484, NT$145,321,869, and NT$28,375,866, respectively.

4.5 BIM Models Integrated with Construction Schedules: 4D Simulations

To clearly grasp the overall construction progress on the dates specified by construction companies, the construction progress schedules shown in the network diagram can be viewed. This enables users to learn about the schedules, float time, and progress of each work item and facilitate subsequent 4D simulations, as displayed in Figure 5.

Figure 5. Parts of the schedule of the case project

After displaying the overall construction progress by using Project, users are required to enter the names and durations of the construction work items in the BIM model by using the Fuzor 4D model task creation menu. Next, 4D simulations are generated (Figure 6), which allows overall construction progress to be observed visually. After entering the schedules for all models, users can preview 4D simulation results in advance and produce smoother 4D simulation animations by adjusting parameters such as the animation speed and illumination level. 4D simulation animations are produced using Fuzor through the following three steps:

(1) Add simulation items: Select the function "4D simulation model" in the menu and turn on the function "4D simulation." Then, add new items for subsequent scheduling.
(2) Set construction dates: Set the overall construction start and completion dates. For instance, in this study, the "start date" and "completion date" were set as "September 23, 2017" and "October 19, 2019,"

respectively.

(3) Add model parameters: After importing the model into Fuzor, click on the models to be scheduled and set the work items and construction dates to facilitate 4D simulations for each work item according to their schedules.

Figure 6. 4D simulation

4.6 Costs Integrated with 4D Simulations: 5D Cost Control

Costs are integrated with 4D simulations to produce BIM 5D simulations. The cost of each work item is incorporated into 4D simulations to form cost curves, which allows them to be generated when each work item was implemented, and corresponding costs are simulated. 5D simulations are performed using Fuzor through the following two steps:

(1) Enter work item costs:When entering costs in 4D simulations, the costs of the component are used as the material cost of the work items. For example, the cost of hoisting the steel bridge in this study was 28,375,866. Work item costs could also be entered using Project or Excel, as shown in Figure 7.

(2) Display cost curves: After entering costs in 4D simulations, select the function "construction shape" to generate cost curves. Cost curves are also displayed during 4D simulations, as illustrated in Figure 8.

Figure 7. Work item costs

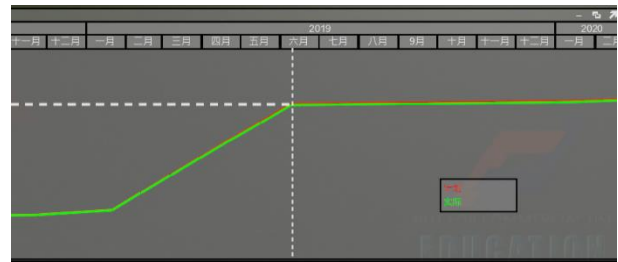
Figure 8. Progress curves of cumulative cost

4.7 5D Simulations Displayed as VR

In this study, mobile phones were placed in VR Boxes, and joysticks were used to move around in the VR environment and present the results of integrating VR and 5D simulations. In general, 5D simulations are displayed through VR through the following three steps:

(1) Initiate connection: Connect to a mobile phone by using Riftcat2.0 and turn on VRidge in the phone to connect it to a computer, as shown in Figure 9.

(2) Place a mobile in a VR Box (as shown in Figure 10) and click the option "connect" in Riftcat2.0 to connect it to VR.

(3) After opening Fuzor Project, use the VR button to connect the VR environment to the VR Box for viewing, as shown in Figures 11 and Figure 12.

Figure 9. Link the phone and the computer

Figure 10. VR Box

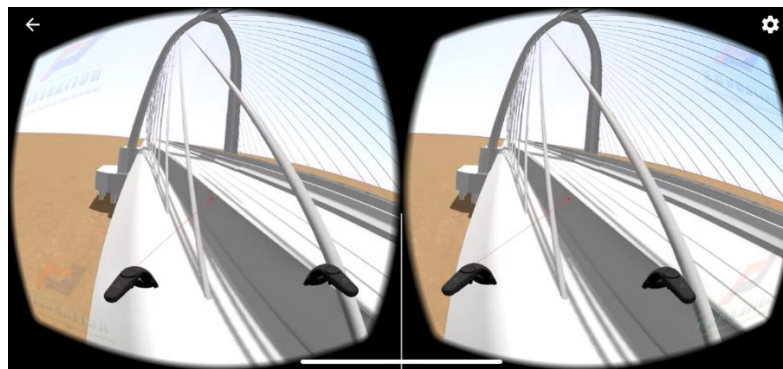Figure 11. VR environment on the computer screen.

Figure 12. VR environment on the mobile screen.

5   Conclusion

5.1   Benefits of Applying Cost Curves

This study combined 4D simulations and costs to display 5D simulations. 4D simulations enable constructions to be viewed as animations, and construction progress costs are viewed as cost curves. Comparing the simulated cost curves with actual cost curves allows identifying actual construction progress and construction costs. This enabls construction companies to determine whether they are ahead or behind schedule on the basis of the discussions and revisions made to elevate construction quality.

5.2   5D Animation Simulations Integrated with VR

Although the group method can be adopted to create bridge models by using Revit and incorporated the models into projects, 4D simulations exhibit the following problem: Only one 4D simulation can be performed for identical components in different work items. Therefore, different component groups must be created for different work items to enable 4D simulations for all work items.

In addition, although higher-standard VR equipment (such as HTC Vive) can produce superior and immersive experiences, it requires using VR sensors, head-mounted devices, and a computer connection, rendering it unfeasible in specific locations. By contrast, this study used VR Box, connected it to a laptop computer and mobile phone, and placed the mobile phone in a VR Box to display the VR, which effectively elevated the applicability of VR displays.

References

[1]   Choi, B., Lee, H. S., Park, M., Cho, Y. K. and Kim, H. Framework for work-Space Planning Using Fou-

Ddimensional BIM in Construction Project. Journal of Construction Engineering and Management (ASCE). 140(9):1-13, 2014.

[2] Lopez, R., Chong, Y., H., Wang, X. and Graham, J. Technical Review ：Analysis and Appraisal of Four-Dimensional Building Information Modeling Usability in Construction and Engineering Projects. Journal of Construction Engineering and Management (ASCE).142(5):1-6,2016.

[3] Zhang, R.and Liang, C. Research on Construction Schedule Control Based on Critical Chain Method and BIM.Journal of Applied Science and Engineering Innovation (ACSS).5(2):47-50,2018.

[4] Jrade, A. and Lessard, J. An Integrated BIM System to Track the Time and Cost of Construction Project: A Case Study.Journal of Construction Engineering,page 1-10,2015.

[5] Chen, H. Y. Guideline Development of BIM/4D Applications for Owners . National Central University Electronic Theses & Dissertations. Thesis,2019.

[6] Chen, Y. X.,Lai, M. H.,Li, Y. W.and Wu, Y. Z. Architect firm BIM technology introduction and effectiveness analysis. Civil and Ecological Engineering Seminar. Page 1-6, Kaohsiung , 2012.

[7] Concord Tech Co .,Ltd. Guangci social housing On-line:https://www.ctc.com.tw/web/Home/NewsInfo ?key=698860839777&cont=158945.