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Effectiveness of 3D Models in Estimating Course

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3-Dimensional (3D) Building Information Model (BIM) can help students' learning in Construction Management (CM) courses. 3D models can help students visualize the information from plans in format of 2D into 3D. Due to this benefit, 3D models have been used in diverse CM courses, and the effectiveness of 3D models in diverse CM courses have been proven to be positive. However, the usage of 3D models in estimating courses has not been clearly proven by existing literatures. Furthermore, accurate estimating requires multiple estimating tasks starting with visualizing building components. There is no existing study on how effective the usage of 3D models is for each of the estimating sub-tasks. This study aimed to explore effectiveness of 3D models in estimating related tasks through students' perception on effectiveness of 3D models in an estimating course at a 4-year college in the U.S. The results of this study show that overall, the 3D models were effective in all the estimating tasks. Also, 'visualizing building components', 'locating building components', and 'identifying building components' are the estimating sub-tasks in which the 3D models were the most effective.

Key Words: BIM, 3D Visualization Skill, Estimating

Introduction

Building Information Models have been used to help students' learning in CM courses. BIM models can help students develop or improve 3D visualization skill which is essential for reading and interpreting construction plans in 2D planes and for planning of construction projects (such as cost estimating and scheduling). The usage of 3D BIM models in diverse CM courses have been studied by many educators and researchers (for example, Aljaboub and Na (2023), Na et al., (2022), and Ghanem (2021)) and proven effective on development or improvement in students' knowledge or skills required. Diverse CM courses in which 3D models were proven to be effective or helpful include print reading course, means and methods course, construction materials course and so on. Most of the existing literatures report positive impacts of 3D model usage from either quantitative or qualitative assessment.

However, exiting studies on 3D models in estimating courses provide mixed conclusion. It is not clear if the usage of 3D BIM models is effective in student's learning or performing estimating assignments in estimating courses. The methods for the assessment of the effectiveness of 3D models in estimating

courses are either student's perception on overall effectiveness of 3D models or measure of accuracy and completion time for quantity takeoff assignments.

Accurate cost estimating can be achieved through multiple sub-tasks and requires many different knowledge and skills, such as print reading, 3D visualization skill, identifying work scope, locating building components, measuring size (or dimension) of building components, determining quantities, pricing, comparison of subcontractors' quotes, etc. Thus, this study aims to explore how effective the 3D models are for each of development of skills required for these estimating tasks. Also, this study plans to identify which estimating task is the most helped by using the 3D models through estimating assignment in an estimating course.

Literature Review

3D Visualization Skill

3D visualization skill (or spatial skill) is "*the ability to visualize and manipulate objects in one's mind*" (Metz et al., 2016) and Hain and Motaref (2020) concluded in their study that the visualization skill can improve students' creativity and spatial understanding. Therefore, training programs targeting spatial skills specifically have been adopted by many 4-year institutions (Sorby et al., 2017).

Construction practitioners use daily the visualization skill for reading and understanding construction documents such as plans. Cost estimating and scheduling need transformation of information from 2D planes in 3D format for construction projects (Williamson and Andrew, 2018). Also, construction project managers are required to have 3D visualization skill to make daily decisions to construct buildings or facilities in 3 dimensions.

Thus, Chen et al. (2011) agreed that 3D visualization skill (or spatial skill) is fundamental in construction education. Also, many other researchers and educators in CM field recognized the importance of 3D visualization skill (for example, Ryoo and An, 2021; Han et al., 2015; Kamat and Martinez, 2000). Furthermore, Glick et al. (2012) noted that students' learning would become difficult and frustrated if students don't have 3D visualization skill.

3D BIM Models in CM Courses

3D BIM models have been adopted and used as a supplementary tool to help students develop their 3D visualization skill in CM education. And many CM educators and researchers have studied the effectiveness of using 3D BIM models on students' learning. The following list shows some of existing studies on the impact of BIM models in diverse CM courses.

- CAD and BIM course: Na et al., (2022)
- Concrete construction course: Irizarry et al. (2012)
- Construction graphics course: Ghanem (2021)
- Estimating course: Gier (2008), and Ghanem (2021)
- Materials and methods course: Ghanem (2021), Glick et al. (2012), and Schreyer (2014)
- Mechanical and electrical course: Aljaboub and Na (2023)
- Mechanics of materials course: Hain and Motaref (2020)
- Plan reading course: Ryoo and An (2021) and Perdomo et al. (2005)
- Structure course: Fogarty et al. (2018)

All of the existing studies above, except for using 3D BIM models in an estimating course, report positive impacts of 3D models in students' learning through quantitative or qualitative measurement(s).

As for the application of 3D models in estimating, Gier's study (2008) measured the effectiveness of BIM model compared to other quantity takeoff methods (traditional hard copy plans only, *OnScreen Takeoff* (OST) software, and combination of OST and traditional method) for quantity takeoff assignments in an estimating class. The effectiveness was measured in two ways: 1) accuracy of quantity takeoff, and 2) time required for takeoff. The study concluded that the usage of BIM helped reduce completion time of quantity takeoff but may not improve accuracy of quantity takeoff.

However, Ghanem (2021) reported that only fifty percent of the surveyed students in the estimating course thought that the 3D modeling helped them. Therefore, the study concluded that the usage of 3D models in estimating course was less effective in students learning than in materials & methods and construction graphics course. The study also noted that the 'less effectiveness' of using 3D models in the estimating course was due to indirect relationship between 3D model usage and estimating skills: the visualization skill might have already been developed in previous courses.

Research Objective and Questions

While 3D BIM models have been adopted and used in many CM courses, only two existing studies (Gier, 2008 and Ghanem, 2021) have explored the effectiveness of 3D BIM models in estimating courses. Based on the results from the two studies, it is not clear if using 3D BIM models in estimating course is effective or helpful in performing quantity takeoff and estimating. Also, it is needed to explore how effective or helpful is usage of 3D BIM models for different estimating tasks (such as visualization, understanding scopes, or quantity take-off).

This study aimed to examine the effectiveness of 3D BIM model usage in each estimating task. This study selected the following five tasks required for estimating and examined the effectiveness of 3D BIM model(s) in each of the estimating tasks.

- To visualize building components from 2D plans
- To identify building components from 2D plans required for estimating
- To locate building components required
- To measure size or dimensions of building components
- To quantity building components (quantity takeoff)

Additionally, this study aimed to continue to measure the effectiveness of 3D BIM models in estimating regarding takeoff completion time and accuracy of takeoff in addition to Gier's study (2008). Thus, effectiveness of 3D BIM models in the following two items were explored.

- To complete quantity takeoff faster
- To get more accurate quantity takeoff

Methodology

3D BIM Models for the Class Term Projects

The estimating course in which this study was administered is the second course for estimating. The first course is for construction documents and (manual) quantity takeoff, and the topics for the second course include unit cost calculation, cost database, productivity, different estimating methods, general conditions cost estimate, subcontractors' bids comparison and computerized estimating. Typically, this course is taken by CM students in the sixth semester or in the second to the last semester at the authors' institution. The (second) estimating course requires students to individually complete estimating and propose a bid proposal for a real construction project as a class term project. The term project includes multiple estimating tasks: work scope identification, quantity takeoff, pricing, comparison of subcontractors' bids, and general conditions cost estimate. The format of the term project is borrowed from the Associated Schools of Construction (ASC) commercial student competition. Since the term project is an individual assignment, only a few construction tasks (or trades, such as cast-in-place concrete, masonry, one of finishing materials, and roofing/insulation) are required for quantity takeoff, pricing, and comparison of subcontractors' bids.

The real construction project used for the class term project is changed every semester, and 3D BIM models for each project is developed by the first author of this study. The project used in Fall 2022 semester was for a new 2-story fire station construction in a college town in Midwest with the cost of around $5 million. The scope of the project includes concrete foundation, masonry wall for stairs, structural steel frames, precast concrete panels, and steel roof framing. Figure 1 shows the 3D BIM models for the project.

The project used in Spring 2023 semester was for construction of a retail store in a mega-city in Midwest with cost of around $4.5 million. The 3-story building in addition to basement includes concrete foundation, structural steel framing, masonry wall, elevator, and steel roof framing. Figure 2 shows the 3D BIM models for the project.

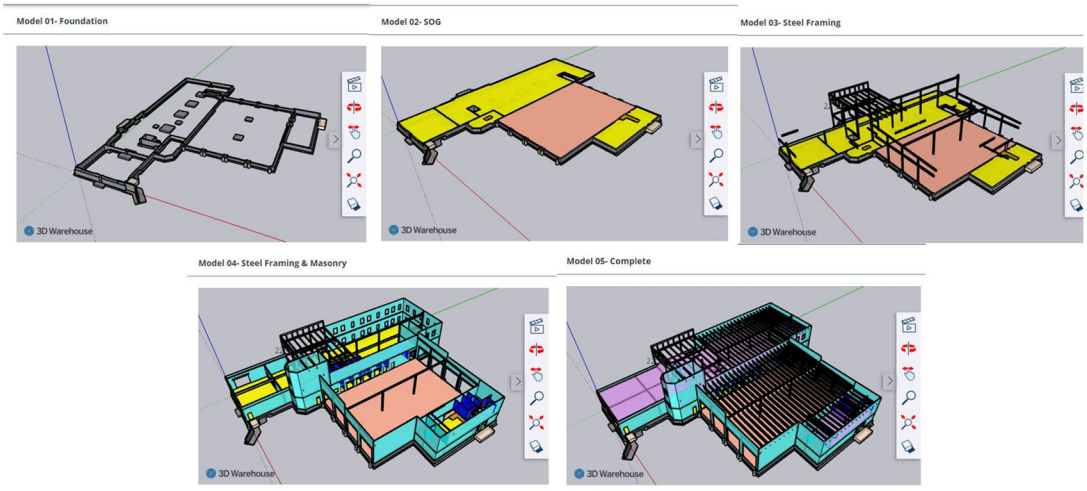

Figure 1.3D BIM models for the class project in Fall 2022

The *SketchUp* software was used to develop the BIM models. As shown in Figure 1 and Figure 2, the BIM models were focused on structural components of the building (such as footing and foundation system and structural steel systems) which the authors believed to be the most complicated parts in

the buildings. The BIM models include sub-models according to the construction sequence or type of building components, which were enabled by 'tag' function in the Sketchup. All the BIM sub-models were stored in the *3D Warehouse*, an open library for *SketchUp* models. Then, those models were embedded in the course Learning Management System (LMS) at the authors' institution. Students were able to interactively review the BIM models through rotating, panning, zooming the models. The interaction in BIM models could help students actively learn (Sampaio et al., 2010).

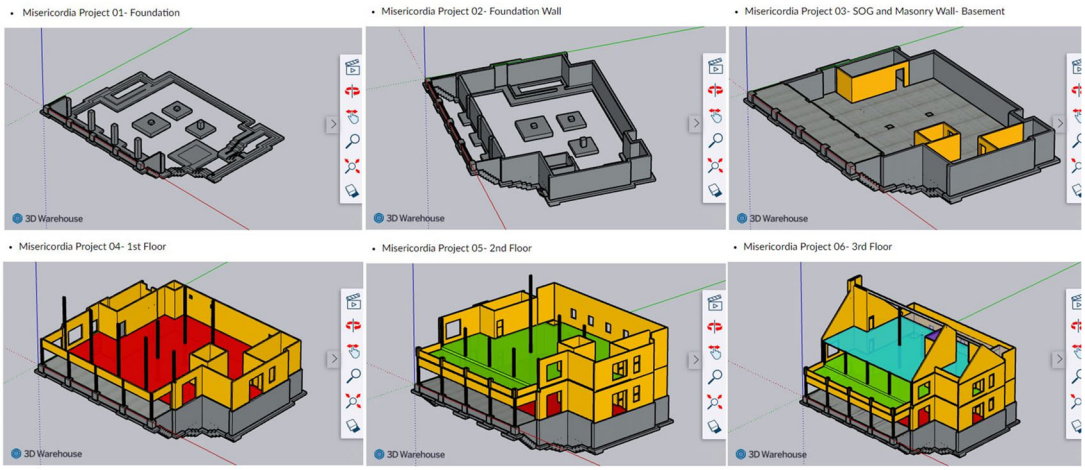

Figure 2. 3D BIM models for the class project in Spring 2023.

Survey for Student's Perception on the Effectiveness of 3D BIM Models

Effectiveness of using 3D BIM models in each estimating task was measured through questionnaire survey after the completion of term projects. Students were asked about how effective the 3D BIM models were for each of the following seven estimating tasks. The answer options for each question include 'Very agree', 'Somewhat agree', 'Neutral', 'Somewhat disagree', and 'Very disagree'.

- To visualize building components from 2D plans
- To identify building components from 2D plans required for estimating
- To locate building components required
- To measure size or dimensions of building components
- To quantity building components (quantity takeoff)
- To complete quantity takeoff faster
- To get more accurate quantity takeoff

In addition, the students were asked how many times they used the BIM models to complete the class term project.

Data Collection

Total 49 responses from the questionnaire survey were collected through two semesters: 38 responses in Fall 2022 semester, and 11 students in Spring 2023 semester. The 38 responses in Fall 2022 were from two sections of estimating course. The survey was administered through an online survey application (*Microsoft Forms*).

Results

Figure 3 shows the students' responses to the question, '*How many times have you used the 3D models to complete the term project?*'. Around 75% of the students had used the 3D models three times or more for the term project. All of 49 students had used the 3D models at least one time.

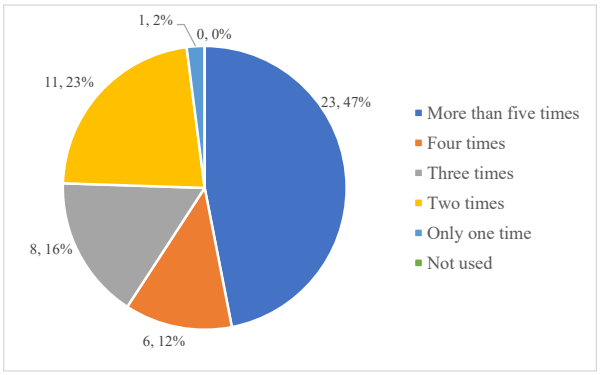

Figure 3. Number of usages of the 3D models for the term project.

Students' responses to the question, '*How effective were the 3D models for each of the estimating tasks?*' are summarized in Figure 4. Students' perception of the effectiveness was measured with the five options, and Figure 4 displays the percentages for each option. It can be interpreted that the 3D models were effective to all the estimating tasks, overall. Based on the both positive response (including 'Very agree' and 'Somewhat agree' responses), the 3D models were the most effective to visualization of building components. Next estimating tasks to which the 3D models were effective were locating building components followed by identifying building components. The estimating tasks to which the 3D models were the least effective was measuring size (or dimensions) of building components.

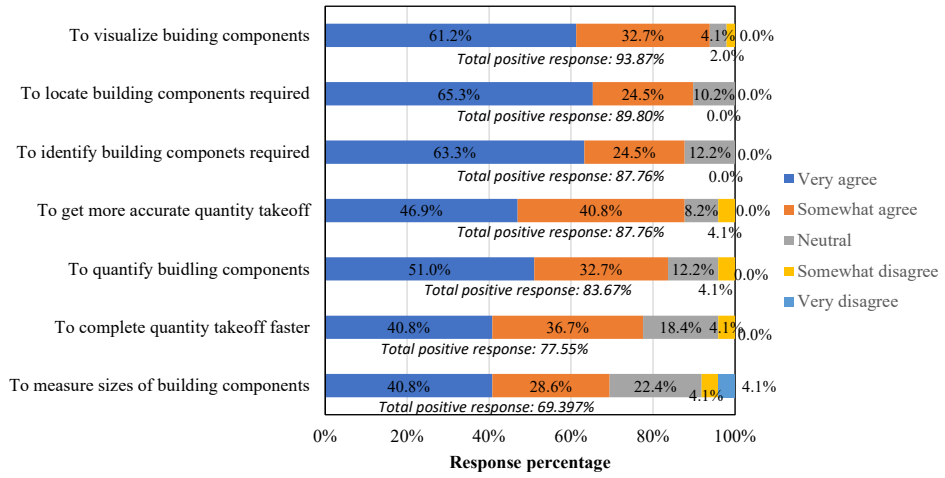

Figure 4. Effectiveness of 3D models- response percentage

The students' responses to the survey questions were converted to scores based on 5 points Likert scale: 5 points for 'Very agree' response, and 1 point for 'Very disagree' response. Then, mean value of students' responses to each survey question is shown in Figure 5. Based on the converted scores, locating building components was the estimating task in which the 3D models were most effective. Next estimating tasks was visualizing building components followed by identifying building components. 'Faster quantity takeoff' and 'more accurate quantity takeoff' were not ranked in the top three estimating tasks helped by the 3D models.

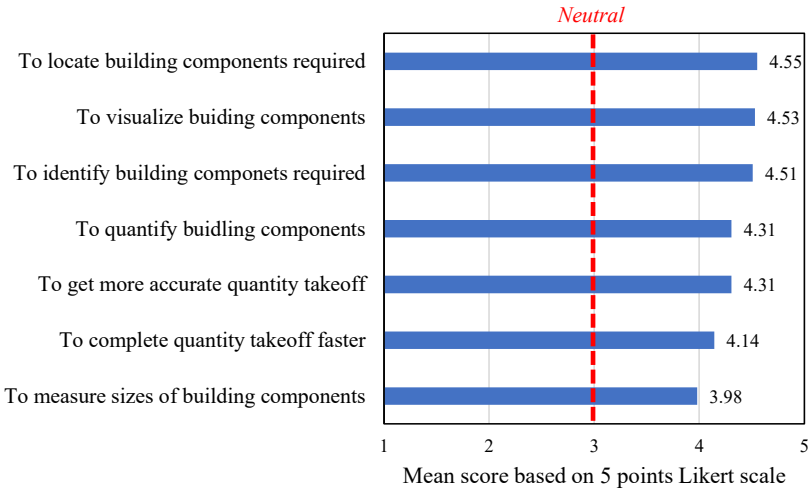

Figure 5. Effectiveness of 3D models- mean value based on 5 points Likert scale

Discussion

The results of the student surveys demonstrate that the 3D models are effective in 'visualizing building components' (the first based on total positive response (Figure 4) and the second based on the 5 points- Likert mean score (Figure 5)). This result does match the results of existing studies (Ryoo and An, 2021; Perdomo et al., 2005).

'Locating building components' and 'identifying building components' are the estimating tasks to which the 3D models can be effective next to 'visualizing building components.' Then, the next group of estimating tasks are directly related to performing quantity takeoff: 'more accurate quantity takeoff', 'performing quantity takeoff (overall)', and 'faster quantity takeoff'.

The CM students at the authors' institution are required to take two related CM courses prior to the estimating (II) course: Construction Graphics course and Construction Documents & Quantity Takeoff (Estimating I course). (3D) visualization skills, reading construction drawings/plans (related to locating and identifying building components), and skills for quantity takeoff can be learned or developed in the previous courses. However, the authors believe that the 3D models could be effective to students' learning process throughout the CM curriculum, and the results of this study are not against the authors' thought. It should be noted that the level of complexity of the projects used for the class term project in the estimating (II) course is higher than those projects used in the two previous courses.

The authors plan to continue to collect data on the effectiveness of 3D models in estimating course in the future.

Conclusions

3D BIM models have been used in diverse CM courses and have been proven to be effective or helpful in students' learning. However, the existing studies on the effectiveness of using 3D models in estimating courses provide mixed conclusions. Thus, this study aimed to explore the effectiveness of using 3D BIM models in detailed estimating tasks in an estimating course. 3D BIM models were developed and provided to help students complete class term projects and their perception on the effectiveness of the 3D models were asked through a survey.

The detailed estimating tasks selected in this study are 'visualizing building components', 'locating building components', 'identifying building components', 'quantifying building components', and 'measuring sizes of building components.' In additions, the students were asked about the effectiveness of 3D models for 'more accurate quantity takeoff' and 'faster quantity takeoff'.

It is concluded that, overall, the 3D models were effective in all the estimating tasks. The estimating tasks in which the 3D models are most effective are 'visualizing building components', 'locating building components', and 'identifying building components.' The next group of estimating tasks for effectiveness of the 3D models are the tasks which are directly related to quantity takeoff: 'quantifying building components', 'faster quantity takeoff', and 'more accurate quantity takeoff'.

While 3D models have been widely studied and proven effective in various CM courses, this is a clarity regarding the effectiveness of 3D models in estimating courses specifically. The findings from this study provide insight to fill the gap in the literature: effectiveness of 3D models in estimating course.

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