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Integrating Virtual Reality (VR) Into Construction Engineering and Management (CEM) Courses-A Case Study

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Construction projects are spatially and temporally dual-dynamic in nature. One of the technical challenges in teaching the construction process is how to describe the spatial layout of construction components. Virtual reality (VR) combined with Building Information Modeling (BIM) technology (BIM-VR) has been adopted in the construction industry for years as a communication tool between stakeholders. The technology can be used to create simulations that allow employees to get an immersive experience of a construction process that has not started, to identify potential problems before construction start, and prepare construction workers for hazards that may occur on construction sites. In this paper, the author reports the findings on evaluating the effectiveness of BIM-VR technology in enhancing students' spatial cognition skills of building and construction components. The evaluation was conducted using two different quantitative approaches. First, the before and after scores of students' spatial cognition skills were measured. The statistics of score changes were used to evaluate the effectiveness of the technology. Then, an assessment was conducted in which a survey was sent to students after completion of the course to gauge their feedback on the effectiveness of the BIM-VR application which had a positive trend.

Keywords: BIM, VR, Revit, visualization, construction engineering and management, education

Introduction

Building Information Modeling (BIM) and Virtual Reality (VR) have recently become useful tools in the architecture, engineering, and construction (AEC) industry (Kim, 2012). These tools provide many benefits including increased communication among stakeholders leading to more efficient project delivery, visualization benefits, lifecycle optimization and management, and greater accuracy for quantity takeoffs (Filzmoser et al., 2015). BIM has become more widely adopted in the industry in recent years, and this calls for increased adoption of classes highlighting BIM uses at the undergraduate and graduate levels (Ferrandiz, et al., 2018).

BIM Application in Education

Several studies have been done regarding the utility of BIM in undergraduate and graduate education. The methods of analysis for these studies include either qualitative analysis, quantitative analysis, or a mix of both. The qualitative approaches to these studies included methods such as surveys, questionnaires, course evaluations, and open discussions with participants in the BIM-related courses (Ferrandiz, et al., 2018). These qualitative measures were meant to gauge student motivation, perceived usefulness of BIM, and improved performance (Hyatt, 2011; Adamu & Thorpe, 2016; Sharag-Eldin & Nawari, 2010). For these studies, the general structure of the course was to introduce BIM as an additional learning tool, then provide the survey or questionnaire at the end of the course for the students to answer. In general, student responses were positive, and they had an increased sense of motivation to use these tools, as well as increased performance when completing projects and assignments (Huang, 2018; Fonseca, Falip, Valls, & Redondo, 2014).

The quantitative approaches for these studies include analyzing participant improvements by comparing scores or percentage of improvement before and after introduction to BIM (Hu, 2019; Irizarry, et al., 2012). Some studies also included applied statistical analysis such as t-tests to check for improvements when BIM was utilized (Kim, 2012; Ferrandiz, Banawi, & Pena, 2018). The study with the heaviest quantitative analysis held the purpose of analyzing the difference between traditional quantity takeoff methods versus methods involving the use of BIM. Their research found that 3D visualization alone can improve the efficiency and accuracy of completing quantity takeoffs. This paper goes into expansive statistical analysis using a multi-attribute utility model which considers evaluations from all four project parameters, which are generality, flexibility, efficiency, and accuracy. The authors conclude by explaining that the BIM-assisted detailed estimating (BADE) tools significantly improved students' ability to generate quantity takeoffs (Shen, et al., 2010).

BIM-VR Application in Education and AEC Industry

Virtual Reality (VR) has been used in classes for years as a supplemental visualization tool. However, the AEC is still exploring possible applications for VR technology. VR provides the ability to further build on BIM application by enabling the participant to be fully immersed in the 3D model virtually. This immersion allows for enhanced spatial recognition. Furthermore, VR when incorporated with BIM will provide added benefits to time, cost, quality, and safety in all phases of construction (Alizadehsalehi, et al., 2020; Ku, et al., 2011).

Many of the studies conducted regarding VR or BIM-VR application in the AEC industry and education field were qualitative in nature. These studies were meant to gauge people's interest and attitudes in using BIM-VR technology. In a study that focused on the application of VR in the construction industry, the authors explored applying VR combined with BIM into the education environment and concluded from student feedback that VR has a positive influence over the learning experience in the construction process (Alizadehsalehi, et al., 2019). In another study, when VR was introduced to AEC professionals with varying years of experience, they all showed positive attitude towards the application of VR for simulation of construction site walkthroughs (Gheisari, et al., 2016).

Some papers had a quantitative approach to the evaluation method. For instance, some researchers developed a VR course to explore its possible applications in engineering education. The paper included very detailed description of the course content, schedule, and equipment utilized. The students were assigned several projects to assess their performance in the course, and their progress

was recorded. However, there was no significant data analysis but only simple observation of student satisfaction and adequate grades (Häfner, et al., 2015). In another paper, the authors explored BIM-VR application in a construction engineering education environment. Student performance was first evaluated in reference to BIM, and if its utilization enhanced performance compared to traditional 2D methods. The students' scores were compared before and after application of BIM, and there was significant improvement in performance. Next, the value of adding VR to BIM was tested, and it was found that the students reacted positively to the experience (Whisker, et al., 2003).

Although these studies measured people's eagerness to use this technology, and some even utilized scores as a quantitative analysis method, more intensive analysis and data is needed to determine whether BIM-VR provides benefit to efficiency, cost, or quality of construction projects.

Problem Statement

Building projects are complex and consist of multiple disciplines including landscape/civil, architecture, structural, mechanical, electrical, and plumbing. Transforming a 2D plan to 3D requires practitioners' full understanding of the spatial layout of the building. Although qualitative data can be useful for assessing people's motivation to use BIM-VR technology, however, little to no research exists on the utility of BIM-VR for construction blueprint reading. Our study plans to use quantitative data to determine if BIM/VR can aid in increasing the efficiency and accuracy of the blueprint reading process. This course and evaluation method were developed to prove the effectiveness of BIM-VR as a visualization and spatial recognition tool, and if it will help newcomers to the industry compensate for minimal experience with the technology application of BIM-VR. Also, the paper covers the gap of studying both BIM and VR applications simultaneously which has been minimally explored. Therefore, the quantitative set of data and results explored in this research provide a useful insight into BIM-VR application.

The Course

**** is an entry-level CAD and BIM course of the CEM program at the University of ****. The course was developed for sophomore students who have little or no prior experience of plan reading and CAD drafting. The primary goal of the course is to help students develop an understanding of construction drawing plans and be familiar with the use of CAD for developing drawings and the use of BIM for modeling, virtualization, and management of construction projects. Upon the completion of the course, the students are expected to be able to: 1) Develop an understanding of basic knowledge of CAD and BIM. 2) Develop a plan, profile, and cross-section views of 3D objects in CAD. 3) Understand how to interpret construction plans. 4) Develop a 3D representation of a facility in BIM.

The research study was conducted in fall 2019. A total of 33 students were enrolled. The course was taught on a lecture and lab basis. The mechanism was that the instructor delivered the technical details in lectures and then the students did hands-on exercises in lab sections.

The labs were typically small exercises and were intended to help students be prepared for the relatively more complex course projects. All assignments are independent work. There was no quiz and exam, so the students were primarily assessed based on the assignments. As shown in (Figure 1), a project-based learning approach was adopted in this course where it was divided into three phases with a project assigned at the end of each phase for evaluation. Also, the figure shows details on the

software used, expected deliverables, scope, and samples of the final product. The blueprints of the projects were all from actual construction projects.

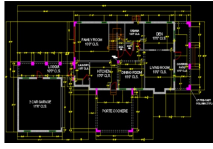

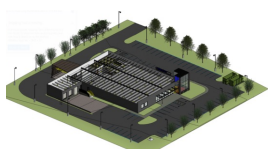
	Phase 1	Phase 2	Phase 3													
Content	Blueprint reading. Developing 2D drawings.	Developing 3D architecture BIM model.	Developing 3D structural and site BIM model.													
Software	AutoCAD 2020	Revit 2020 + Enscape	Revit 2020 + Enscape													
Deliverable	Project 1: a small residential house 2D plans + weekly labs	Project 2: a small residential house 3D model + weekly labs	Project 3: a small commercial building 3D model + weekly labs													
Purpose	<ol style="list-style-type: none"> 1. Practice reading plans. 2. Familiarize students with different views (plans, sections, elevations and callouts). 	<ol style="list-style-type: none"> 1. Practice transforming 2D to 3D. 2. Develop a basement plan to participate in interior design. 	<ol style="list-style-type: none"> 1. Build a 3D model from a complete set of drawings and specifications. 2. Familiarize students with reading structural plans (ex. foundation and steel framing plans). 													
Product																
Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16

Figure 1. The workflow of the CAD and BIM course

Methodology

Most students of the class were sophomores and had no relevant experience in the industry yet. The ability to read and interpret blueprints correctly became a useful and important skill for the students. In this case, VR was integrated into the class in combination with BIM to enhance their spatial cognition skills. All students in this class were provided with chances to explore the simulated immersive environment of the sample projects as well as their models (Figure 2). The intent is to help students understand the spatial relationship of the projects and avoid errors in blueprint reading and modeling. Our VR method is to use Oculus Rift plus Revit/Enscape. Oculus Rift is the first generation of Oculus VR products (Figure 3a). It has a resolution of 1080×1200 per eye. Enscape is a Revit plug-in and was used for rendering and enabling the immersive background (Figure 3b).



Figure 2. Virtual walkthrough of student project.

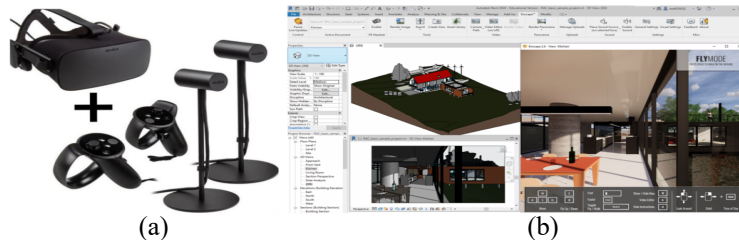


Figure 3. (a) Oculus Rift Virtual Reality Headset and (b) Revit + Enscape Interface

The performance of BIM-VR in enhancing students' spatial cognition skills was evaluated by the two tests:

Test 1: the students were provided with one floor and four elevation plans of a one-story building (Figure 4) at the end of phase 1 (Figure 1). Then the students were required to sketch the same rooftop plan of the building. The students were provided chances to explore the model of the same building using BIM-VR after test1.

Test 2: one-floor plan and four elevation plans of a similar building were assigned to the students (Figure 5) at the end of the semester in phase 3. At this time, the students had completed Project1 and several BIM labs, so they had more exposure to BIM and VR. The students were asked to sketch the rooftop plan of the second building. The test solutions can be found in Appendix A.

The student answers were quantitatively assessed. The students got credit for every correct line. The student scores were calculated by dividing the credits earned by the total credit. To compare the test results, a one-tailed paired T-test was conducted at a significance level of 0.05. The null hypothesis H_0 is $\mu_D=0$. The alternative hypothesis H_a is $\mu_D < 0$, where μ_D is the expected difference between X and Y, the score from the first and the second observations respectively; D is the difference between the two tests. 19 out of 33 students in this class participated in both tests. The data from the other 14 students were excluded from the paired T-test.

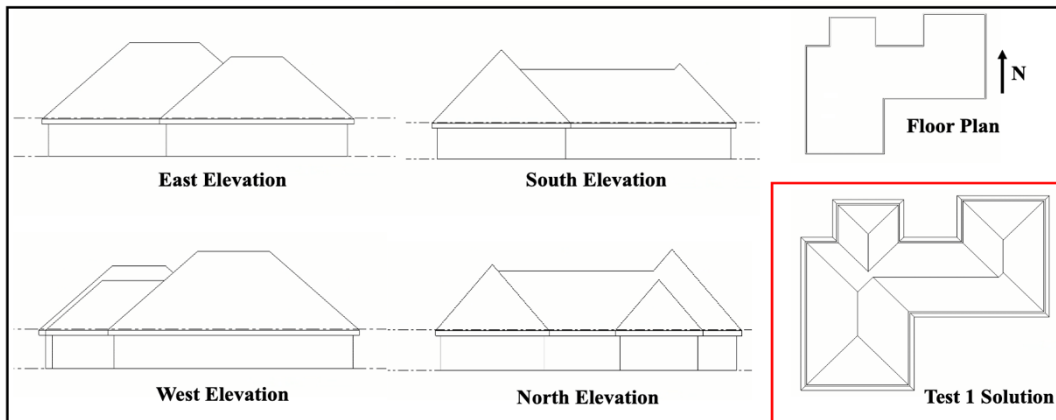


Figure 4. The floor and elevation plans of test 1.

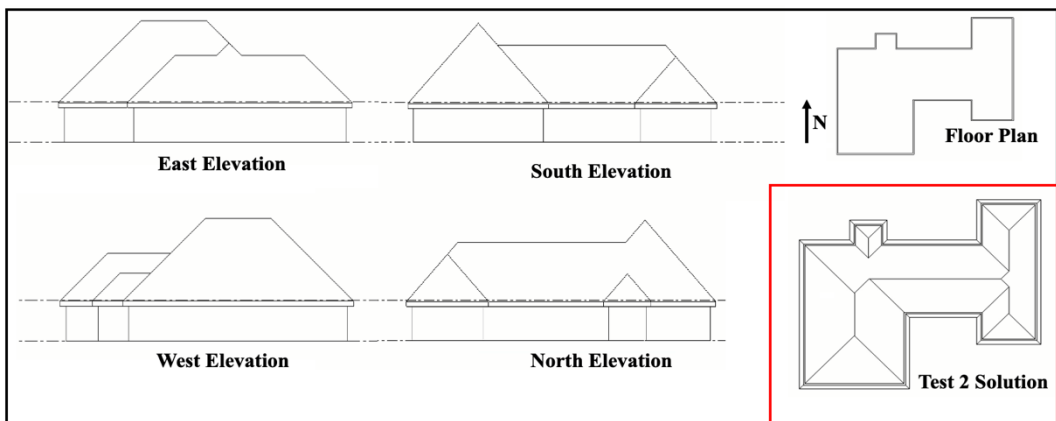


Figure 5. The floor and elevation plans of test 2.

Results and Discussion

The score of the two tests and the result of paired T-test were summarized (Figure 6) and (Table 1) respectively. The P-value is $4.8E-06$, which is much less than the significance level of 0.05, thus the null hypothesis was rejected. In other words, the BIM-VR application did have a positive impact on enhancing student spatial cognition skills. The increase of the mean is more than 17%. It was also found that the variance of the test 2 score was much less than that of the test one, which indicates that after the BIM-VR application, the overall spatial cognition level of the sample students transitioned from a dispersed state to a relatively more concentrated state. This improvement can also be attributed to the fact that students could read the plan more proficiently later in the semester. This will be further investigated through collecting more data in phase 1 and phase 3 without using BIM-VR. As a supplement to the first statistically motivated quantitative study, another quantitative study was also conducted in which a survey on the VR application was sent to the students at the end of the semester. 30 out of the 33 students responded to the survey. The survey consists of 12 questions which a small summary of the intent behind and student feedback is shown in (Figure 7).

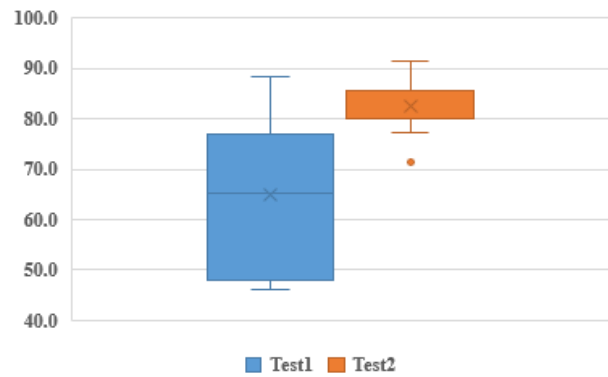


Figure 6. Box Plot of Test1 and Test2 Score.

Table 1		
<i>Paired T-test Result</i>		
Test #	Test 1	Test 2
Mean	64.98	82.41
Standard Error	3.35	1.26
Median	65.38	80.00
Standard Deviation	14.61	5.49
Sample Variance	213.50	30.17
Range	42.31	20.00
Minimum, Maximum	46.15, 88.46	71.43, 91.43
Confidence Level (95.0%)	7.04	2.65
Hypothesized Mean Difference	0	
Df (18)	18	
t Stat	-6.08	
P(T<=t) one-tail	4.8E-06	
t Critical one-tail	1.734064	

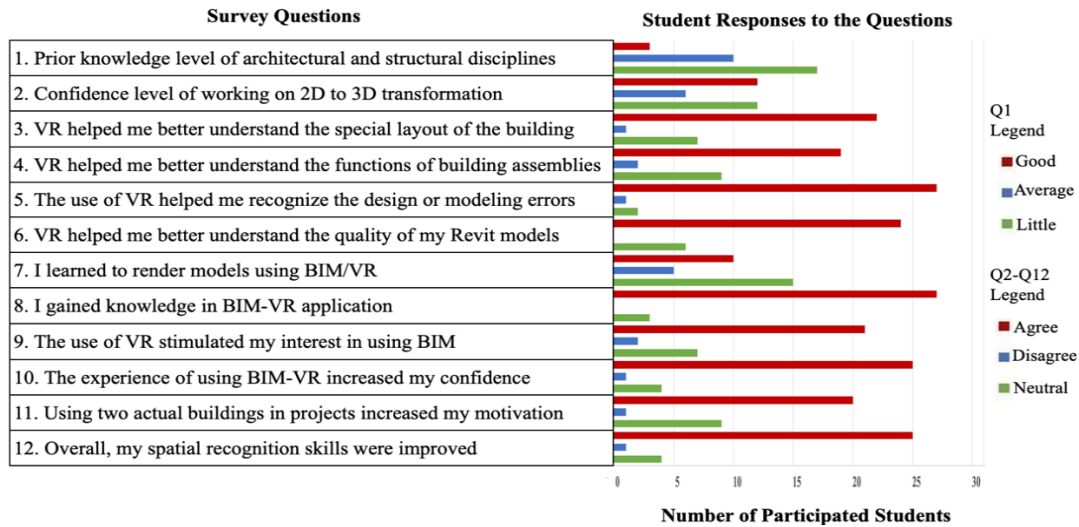


Figure 7. Student Responses to the survey on VR application (Responded/Enrolled=30/33)

Key findings of the questionnaire are as follows:

More students tended to agree that they have little to average relevant prior relevant knowledge before taking the course. It was surprising to see that more than one-third of the sample students believed that they could create an error-free model without checking them in 3D view or VR. But in the later actual practice, we found many modeling errors when doing the virtual walkthroughs indicating that the students were overestimating their abilities. Most students found BIM-VR an effective and useful tool that increased their interest in BIM and prepared them for their future careers. Overall, we received positive feedback from the students.

Conclusions and future study

The paper presents a case study of integrating BIM-VR integration into one entry-level construction engineering course. The intent is to provide an immersive environment of construction projects to help students better understand spatially complex building systems. Two quantitative assessments were conducted. In the first quantitative study, the students' spatial recognition skills were rated before and after BIM-VR application through a rooftop plan test respectively. A paired T-test was used to compare the results of the two tests. The statistics result indicates that the BIM-VR solution significantly improved the students' skills of interpreting blueprints. As for the second quantitative study was conducted through a survey with twelve questions. Overall, positive feedbacks were received from the students. The presented course is the first course that has implemented VR technology in the CEM curriculum at the University of ****. A limitation was that the data size was limited to the number of students participating in the class, which was only 33 while a larger sample size would provide for better and more concrete results. In the future study, when there are enough participants, a control group and an experiment group would have been possible to set up. This would have helped with clarifying if the reduced variance in test results was due to increased experience throughout the course, or due to BIM-VR application. As part of the long-term plan, BIM and VR are going to be integrated into the other construction courses, including construction means and methods,

construction safety, and senior design. BIM-VR implementation throughout the CEM curriculum is going to be further studied and its effectiveness will be evaluated depending on the application within the curriculum of the course. Finally, the paper focused mostly on the addition BIM and/or BIM-VR provides to blueprint reading when compared to 2D. However, BIM was not compared to BIM-VR application to evaluate the addition VR provides when combined with BIM, this will be addressed in future studies and research.

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