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IMMERSIVE VR IN THE CONSTRUCTION CLASSROOM TO INCREASE STUDENT UNDERSTANDING OF SEQUENCE, ASSEMBLY, AND SPACE OF WOOD FRAME CONSTRUCTION

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EDITOR: Turk Ž.

Jason Lucas, Assistant Professor
Clemson University
jlucas2@clemson.edu

SUMMARY*: The use of Head Mounted Displays (HMD) to view Virtual Reality (VR) environments has increased in the recent years with the introduction of high-quality economic devices that offer a quality user experience. Within the design and construction industries, the use of HMD-VR is growing and has proven to be a powerful visualization tool for helping clients understand space. This research is looking at the potential introduction of HMD-VR into the construction education classroom in the context of wood frame construction assemblies. A study was conducted using commodity HMD-VR headsets powered by mobile devices. A pre and post survey was conducted by allowing the students to navigate around a virtual environment using the device, document perceptions pertaining to VR in the classroom and the students' ability to understand qualities of the model's construction when in the simulated environment. This paper discusses the development of the HMD-VR environment, the user experience, and the results of the pre/post surveys. The results conclude that the students had an overall favourable view of implementing the technology into the construction curriculum. Additional survey analysis is included in the paper.*

KEYWORDS*: Virtual Reality, Immersive, Construction, Education, Head Mounted Display*

REFERENCE: *Jason Lucas (2018). Immersive VR in the construction classroom to increase student understanding of sequence, assembly, and space of wood frame construction. Journal of Information Technology in Construction (ITcon), Vol. 23, pg. 179-194, http://www.itcon.org/2018/9*

1. INTRODUCTION

Hands-on and active learning has been identified as beneficial in courses that include technical material because it requires a higher level of thinking (Burrowes, 2003; Michael, 2006). Virtual reality (VR) is a computer simulated environment that allows for user interactions that can allow students an active learning environment (Sala, 2016). This research is looking at the use of immersive VR to augment undergraduate construction education in terms of developing students' technical understanding of construction sequencing, assemblies, and spatial conditions related to wood frame construction.

Traditional hands-on learning, site visits, and practical work experience is viewed as a very power experiential learning tool for construction management students. However, limited resources including hands-on learning space, material cost, and time required for site visits all constrain the extent of these activities in undergraduate construction education. Additionally, there is a growing need to provide experiential learning activities for distance learning students who are not centrally located to take advantage of in-person experiences. To address these constraints and offer more interactive and experiential learning, immersive VR is explored as a potential solution. Relatively inexpensive VR systems have emerged for entertainment over the past few years and can serve as a platform for interactive student learning. Simulations that include simple activities, observations, and virtual site tours are envisioned as part of an immersive VR construction education curriculum.

This paper discusses preliminary explorations into the use of VR to assist in teaching wood frame construction techniques and processes within a construction management curriculum. Specifically the understanding of construction assemblies and spatial qualities of a wood framed structure are examined. An immersive VR simulation utilizing commodity Head Mounted Displays (HMDs) was developed. Students were allowed time to explore the simulation and provide feedback. Student's understanding of materials, components of construction, and overall spatial qualities of the model within the VR environment compared to traditional means that are currently used in the classroom are also explored. Preliminary findings, observations, and a path forward for developing VR based content for construction education is included.

2. BACKGROUND

2.1 Virtual Reality for Learning

Immersive VR is valuable because it places the participant in a scenario and gives them a presence in a place where they are not physically located. Immersive VR with HMDs has positive effects on cognition in terms of memory recall because it allows for the brain to encode experiences much as if they physically happened (Repetto et. al, 2016). VR and simulation allow for experiential learning through specifically designed environments. Simulated experiences are comprehended either through apprehension, meaning actual participation in an experience, or through comprehension which requires abstract conceptualization. The experiences are then transformed through intention by internalized reflection of an experience or extension through active experimentation. Both intention and extension lead to a knowledge gain by the learner (Sewchuk, 2005). This comprehensive learning in a 3D virtual environment allow learners to retain more of the complex and dynamic nature of 3D phenomena pertaining to problems in the real world as opposed to other forms of conceptualization (Roussou et al, 2006). This is attributed to the user's ability to engage the environment by looking and walking around the simulation to change their view of the environment while observing complexities and relationships that are not as easily seen by other methods (Winn et al, 2002). 3D environments can also increase learners' engagement and motivation in the learning tasks while offering a more enjoyable experience (Winn et al., 2002; Youngblut, 1998). Additionally, evidence suggests that freely navigating around an immersive environment stimulates brain activity by creating a higher level of cognitive encoding within working memory which correlates to greater success with cognitive retrieval (Jaiswal et al, 2010).

There are various levels of immersion within virtual environments that have an effect on learning. Byrne (1996) shows that the level of interactivity within the learning environment was the most important factor, not level of immersion, when learning about abstract concepts. However, Rousou et al (2016) suggest that fully immersive environments help aid in simulated problem solving and Winn et al (2002) found that students in an immersive environment performed better when learning about dynamic processes. Heydarian, et.al. (2014) found that immersive virtual environments provide a similar sense of presence and understanding of space as physical mockups. Zou et al (2016) suggested that a similar emotional response can be gained through an immersive simulation as if it was a real-life event.

The proposed simulated learning environments offer free navigation of an environment where the student will have control of the navigation and certain conditions within the environment. This provides for comprehension through apprehension by virtually walking through and interacting with the environment. Additional, the students will have control of the construction sequence of future simulations where sequence steps and assembly components are visualized in a self-paced environment.

2.2 Challenges of Immersive Learning Environments

A challenge for learning within a virtual environment is that the learner needs to master the interface and accompanying interaction tools before using the environment (Schittek et al, 2001). If students were to get frustrated while using the technology or have a bad experience with technology that can influence their motivation in using the new technology for learning (Granito and Chernobilsky, 2012). Navigation and wayfinding are important so the learner does not become de-motivated to learn and explore the environment.

Another issue when it comes to immersive VR and the use of HMD-VR is physical and physiological discomfort, often termed cyber-sickness. Cyber-sickness, sometimes called simulation sickness, is similar to motion sickness but is caused by the use of a virtual environment to stimulate the brain into feeling as if it is in motion (LaViola, 2000). Cyber-sickness is hypothesized to occur from sensory conflict in the brain and tends to worsen with prolonged exposure (Kennedy et.al. 2000). One common theory for the cause of cyber-sickness is a sensory mismatch, where the vestibular system which is responsible for spatial orientation does not feel the same effects as the visual stimulation within the VE, causing the feeling of discomfort (Dennison et.al, 2016).

Davis et.al. (2015) believe that the feelings of cyber-sickness increase when the realism of the environment increases. Dennison et.al. (2016) summarized multiple research studies in concluding that cyber-sickness includes: vomiting, nausea, light-headedness, facial pallor, and sweating. Vinson et. al. (2012) found that users prone to motion sickness are also more prone to cyber-sickness affects. Therefore, they recommend having those who self-report as prone to motion sickness be screened out of a study.

Not all studies identify the extent of exposure to immersive VR having the same effect on the rate of cyber-sickness but prolonged exposure typically had longer lasting effects (Cobb et.al, 1999; Regan and Price 1994). Regan and Ramsey (1994) identified symptoms of simulation sickness lasting up to five hours after exiting the virtual environment simulation. However, Kennedy et.al. (2000) found that multiple sessions of exposure actually lessens the effects of cyber-sickness suggesting that the brain can adapt and adjust for the sensory conflict.

2.3 Design and Construction Education and Training in VR

For design and construction, virtual reality and simulation has been used to help students increase their awareness and advance their understanding on a variety of concepts. Immersive VR has been explored through various education domains when time, inaccessibility of the physical event, safety due to dangerous situations, and ethical concerns are barriers to physical participation in the event (Freina & Ott, 2015).

Within an immersive environment, Fogarty et.al. (2015) utilized both CAVE-type VR and HMD-VR as a substitute for hands-on lab space to help students learn about structural components and assemblies in static models and more advance design concepts of load limit and buckling within dynamic models. Students identified better understanding and ability to visualize these concepts because of the interactive nature of the environment. In other work related to structural design and concepts, Luo and Chhabda (2018) developed an online virtual lab for structural design and analysis that allowed students to customize designs of structural beams and observe a virtual "lab test" to show how the design reacted to various load conditions.

For understanding construction management processes, Messner et.al. (2003) developed a system within a CAVE environment to allow students to review 4D Simulations that they created and stated that students were able to better critique the models they and others made in the full-scale virtual environment as opposed to 2D representations of the model. Pariafsai (2016) developed an interactive game that focuses on construction management processes. Students showed improved results in problem solving and critical thinking when able to observe risk-free outcomes to decisions that alternatively would have negative real-world impacts. Sampaio et.al.

(2010) identified the impact on student understanding of construction methods and assemblies in relation to bridge models in civil engineering education when utilizing a model that can be easily deconstructed within a virtual environment.

Construction safety is another arena where 3D simulation and virtual reality have been explored. Hilfert et.al. (2016) examined the use of HMDs to test human behaviour in several unsafe work scenarios that are common in practice when training new employees. This allowed the subjects to experience unsafe work scenarios without being put in danger. Pedro et.al. (2016) incorporated virtual content into a construction materials classroom to integrate safety information through mobile based virtual simulations. Materials to compliment a traditional lecture were used in addition to a hazard identification game module that gave students an opportunity to practice hazard recognition and response within a virtual environment. Preliminary trials and prototype development indicated benefits to the students understanding of safety concerns on a dynamic jobsite.

In terms of spatial understanding, Paes et.al. (2017) examined architectural students' understanding of spatial perception between a non-immersive VR system on a work station and a stereoscopic panoramic projection with results suggesting the larger scale display provided a more favourable perception of space within the architectural model. These findings are similar to case study observations where CAVE-like VR projection systems were utilized for client and user design review in healthcare design that showed benefits of greater understanding of spatial conditions by the future occupants of the facility (Lin, 2018).

The incorporation of HMD-VR solutions in construction education is minimal. Most likely from the newness of affordable technology and the need to develop appropriate readily available and usable content.

3. RESEARCH MOTIVATION

The purpose of the study is to take affordable commodity devices that are readily available on the market and explore their potential for use in construction education. The Samsung GearVR 2nd Generation and Samsung Galaxy S7 mobile device were chosen. At the time of procurement they were the best balance of resolution and processing power at a lower cost than tethered options. Untethered devices, meaning they do not require a hardwire connection to a computer, were desired because of the need for mobility to be brought into the classroom. Untethered devices also allow for the potential for distance learning students to procure the same technology with relative ease and a phone-based platform allows the mobile device to be used for more than just the virtual simulations. Cost of these systems is also becoming lower with higher quality resolution and commercial stand-alone systems are becoming available. As the technology grows, students will be able to purchase their own headset for the cost of a traditional textbook. The drawbacks taken into consideration when choosing the commodity HMDs include lower processing power and lower visual resolution as compared to a tethered device. However, with the developed content type, these are surmountable barriers. The effects of the lower processing power and visual resolution are measured with the post-simulation survey in terms of identifying amount of movement lag and accompanying distraction as well as the user's perception of the model's visual quality.

The capabilities of the technology to offer an experiential learning experience without the need for a physical mock-up is one of the motivations for utilizing VR technology in the construction education classroom. Therefore, with the lack of significant materials lab space and other necessary resources for student hands-on interactions the simulation will substitute a physical experience. Future expansion can incorporate 360-degree video instructional tutorials and "virtual" field trips. The culmination of all these technologies can assist in developing online and distance education learning content and offer experiential learning to non-traditional students. Over time, a library of new simulations with various types of construction can be documented in immersive environments and serve as a key piece of the construction curriculum.

Informed content creation for use in construction education is one of the objectives of the research. The current study is exploring initial reactions of students' use of the HMD-VR as a learning environment, examining students' perceptions and understanding of various environmental qualities within the simulation, and identifying where the students envision HMD-VR content being most applicable to the curriculum content. As a result of this phase of research, plans for moving forward in terms of appropriate content creation and necessary testing is identified.

4. METHODS

This preliminary study used a quasi-experimental approach with pre/post-test surveys to gain an understanding of how construction management students would react to the use of HMD-VR simulations to supplement typical classroom learning. The intervention within this study was the actual use of the HMD-VR simulation. The first survey documented basic demographics and prior preconceptions as well as a review of rendered images from the model for the students to answer questions about.

After completing the first survey, participants received a description of how to navigate through the environment and what to expect while in the environment. They then took 5-8 minutes to explore the environment. A relatively short duration of exposure was identified as to minimize the impact of sensory conflict that could cause cyber-sickness. The environment was also not overly complex, so this should be enough time to adequately review the model. Participants were also asked to stay seated in a typical armless classroom chair so they had a "grounding" to the physical environment which may help minimize feelings of discomfort.

The second survey, taken after using the simulation, included some additional questions about the spatial qualities of the simulation, navigation and wayfinding, any discomfort they felt, the general usability of the environment, and feedback as to where the technology can fit into the curriculum. The purpose of the comparison between rendered images and the HMD-VR simulation was to identify traditional learning materials utilized in the courses as a means of comparison to the simulated environment. Rendered images from the same model used in the simulation were used to represent traditional learning materials. This was done to prevent real-life images or model quality within the simulation from having an influence on the participant responses. Future analysis can examine various levels of VR simulation including desktop and 2D non-immersive mobile simulations and their effect on student comprehension once content type is identified and developed.

5. HMD-VR SIMULATION

5.1 Simulation Development

The simulation was developed and programmed in Unity version 5 and later updated to Unity version 2017.3.1f1 (Unity, 2017). Unity is an application development software and game engine capable of building multi-platform based 2D and 3D games and simulations that allows for the creation of 3D virtual simulations that can be deployed in the Samsung GearVR (Samsung, 2017) and Oculus Rift (Oculus, 2017). For VR application development, Unity allows different types of models to be brought into the development environment as assets. These assets and other prefabricated gaming entities can be programmed for user interaction. Once the content was created and programed within the Unity preview environment it was built into an application and deployed to the Samsung Galaxy S7 and viewed in the GearVR (Fig. 1).

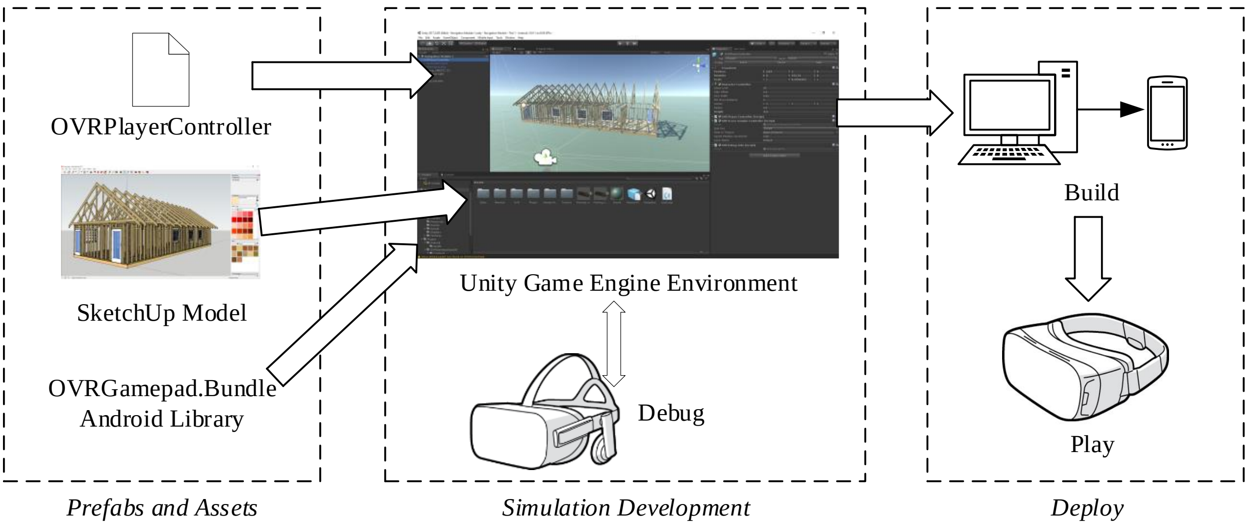

FIG 1: Simulation Development Workflow

A framing model for a house was developed using SketchUp (Trimble, 2017). SketchUp models saved as version 8 or earlier (as well as some other modeling file formats) can be imported direction into Unity as an asset and do not have to be converted. Within SketchUp the objects were drawn as components and groups were used to link similar components of an assembly together. When the model is brought into Unity the model component hierarchy tree is bought in as well. This allows for easily identifying model components for additional programming and interactions. Additional model elements can be added with basic 3D modelling functions provided within Unity. Materials of modelled objects can also be modified within the Unity environment. Additional, libraries of prebuilt assets called "prebuilds" are available for free and purchase through the Unity Asset Store.

Prebuilds were used that allow for the simulation and navigation controls to be compatible with the Oculus Rift and GearVR. These were developed by the Oculus Developer Community (Oculus, 2017), downloaded, and imported into the Unity project. The *OVRPlayerController* is a developed prefab asset from Oculus that includes code modules to allow for head-tracking and navigation input from various controllers to control the simulation within the Oculus Rift and Samsung GearVR. The player controller can be customized depending on the needs of the developer for each specific environment. To offer a more user friendly and less harsh user experience, head-bob, start and stop step differences and "step sound" audio that could influence user experience were all turned off because addition movement in the form of head lag, rendering jitters, or non-user induced change in the view within a simulation can increase the possibility of symptoms of cyber-sickness (LaViola, 2000). Additionally, care was taken in setting user movement to only occur when the user was pushing on the joystick and to select a moderate avatar velocity that was not too slow to be frustrating but not too quick to cause disorientation. So et.al. (2001) identified that an increase in avatar velocity increases vection, or the sensation of self-motion produced by visual stimulation. Bonato et.al. (2008) identified that a change in vection seems to increase cyber-sickness so acceleration and deceleration not under the control of the user were also eliminated from the player controller.

During development, a hardwired Oculus Rift was used to debug the programming. Once the program is complete it was built on the Samsung Galaxy S7 device and then viewed through the Samsung GearVR. For the purposes of the research, the program was built directly on the mobile devices. However, when content is finalized it can be hosted into the Oculus store and downloaded for use on any compatible device offering widespread dissemination to a broader base.

5.2 User Experience within the Simulation

The user interacts with the simulation environment by head movement and an X-box style controller. Upon activating the simulation, the user is placed in front of the framed house from a perspective as if they were standing about 3 meters from the corner of the building (Fig. 2). The user navigates through the environment by using the joystick on the controller for front to back movement. The GearVR's internal head tracking sensors allow the user to change their view of the model by moving their head up/down and side-to-side (Fig. 3). As the user navigates through the environment, they can examine the components of construction and walk through the simulated jobsite.

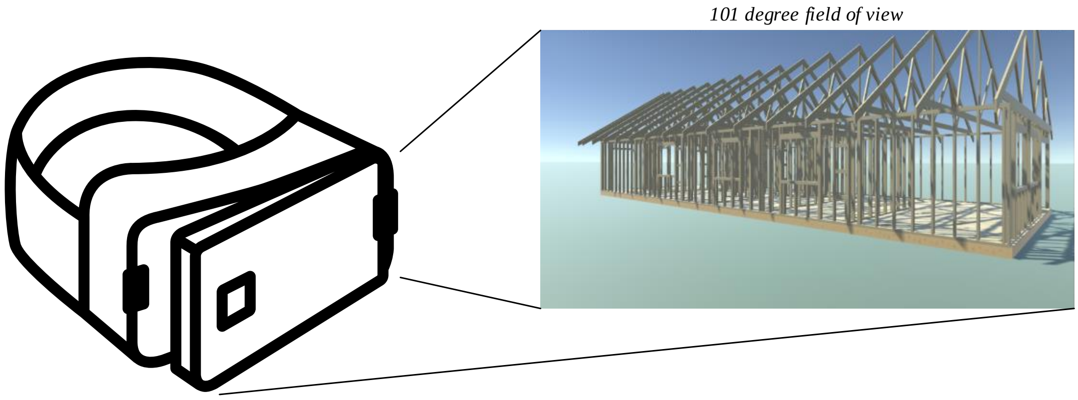

FIG. 2: Simulation Environment

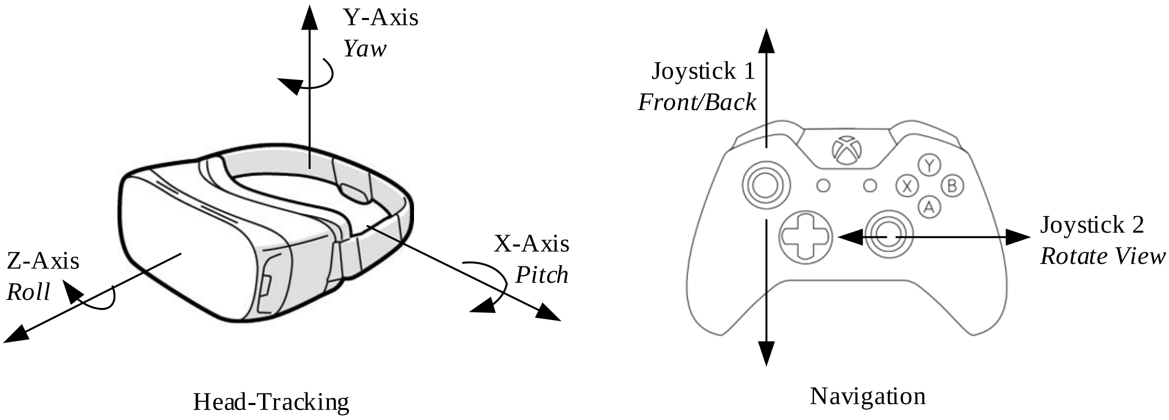

FIG. 3: User Navigation through Environment

5.3 Survey 1

The first survey collected data related to user demographics, perceptions of VR, and spatial understanding of 2d rendered images. The demographic questions include the respondent's level of education (Freshman, Sophomore, etc.) as well as extent of prior use of controller-based video games. Controller-based video games were defined as computer or console based systems that utilize a hand held controller (e.g. X-Box, PlayStation) to control player interactions in the game. Lastly, respondents were asked about prior experiences with VR-HMDs, system they used, and for what function.

Students were invited to participate from three different classes within the Construction Management program at one university. A total of approximately 110 students were enrolled in the three classes (some students in more than one of the classes). Based on findings in literature as noted above, those who were highly prone to motion sickness or had any issues with cyber-sickness during any prior VR-type experience were asked to not participate. Otherwise, there was no criteria besides being a student in the program to take part in the study. Basic demographics of who responded are shown in Table 1.

TABLE 1: Summary of demographics (percentages represent "of total respondents")

Level	**Participants**	**Prior Video Game Use**	**Prior HMD-VR Use**	**Positive Response HMD-VR in Const. Ed.**
Freshman	7 (28%)	5 (20%)	3 (12%)	7 (28%)
Sophomore	12 (48%)	12 (48%)	5 (20%)	12 (44%)
Junior	4 (16%)	4 (16%)	2 (87%)	4 (16%)
Senior	2 (8%)	2 (8%)	1(4%)	1 (4%)
Total	*25 (100%)*	*23 (92%)*	*11 (44%)*	*23 (92%)*

Also as part of survey 1, respondents were given a series of rendered images of the same model used in the simulation environment. The renderings represented typical views and images of components that are found in traditional lecture material and the course text. Respondents were asked questions about the spatial qualities, materials used, and components of construction. Question 1 asked the students to rank the ability of the rendered images to provide an understanding of spatial qualities of the wood frame structure within the context of scale of perceived space as it relates to overall size of rooms, size of structural members, and scope of work. Question 2 asked about their ability to distinguish the different materials that were used in the wood frame structure (e.g. dimensional lumber, wood subfloor panels). The last question asked about their ability to identify, distinguish, and understand the components of wood frame construction (e.g. header, roof truss, studs). These questions were provided on a Likert scale where 1 was ranked as "not at all", 3 was "neutral", and 5 was "very well".

The results of these three questions are shown in Table 2.

TABLE 2: 2D Image Conveyance of Information

Question Topic	**Mean**	**Mode**	**Range**	**Stn. D**
Q1. Spatial qualities and structural scale	3.89	4	2 to 5	0.737
Q2. Materials used in wood frame construction	3.85	3	2 to 5	0.970
Q3. Components of wood frame construction	3.74	4	1 to 5	1.003

5.4 Survey 2

Survey 2 was completed by the respondents after they participated in the simulated environment and contained three categories of questions: understanding of constructed assembly (Table 3), usability (Table 4), and comfort level (Table 5). Descriptive statistics were used to summarize the results of all questions in these three categories. Respondents were also asked an open-ended question of where they would best see the technology used in construction education.

For identifying the understanding of constructed assemblies, the same questions asked from the first survey was used but asked about the simulation's influence on the student's understandings. The results are shown in Table 3. In addition, question 4 asked about the feeling of "presence" within the simulation where presence was defined as "an active and embodied experience where you feel as if you are in and interacting with the space".

TABLE 3: Understanding of Constructed Assemblies

Question Topic	**Mean**	**Mode**	**Range**	**Stn. D**
Q1. Spatial qualities and structural scale	4.72	5	4 to 5	0.449
Q2. Materials used in wood frame construction	4.72	5	4 to 5	0.449
Q3. Components of wood frame construction	4.48	5	3 to 5	0.640
Q4. Developing a sense of presence within the space	4.04	4	3 to 5	0.824

Open-ended responses were also allowed for comments on the visual appearance of the model and the ability of the user to understand space. Those comments are paraphrased and grouped below:

- The simulation helped to develop a sense of feeling of the space
- Understand the materials and environment better than on paper and with typical lecture material
- Better understanding of the scale of the structure
- Walking through the simulation gave the space more meaning

The second part of the survey dealt with questions pertaining to usability of the simulation. Questions 5 and 6 asked for Likert rating of 1 to 5 with 1 being Very Easy and 5 being Very Hard. Questions 7 asked about the visual clarity of the model where 1 is Very Clear and 5 is Unclear to the point where it was difficult to understand the intent of the model. Lastly, Question 8 in this section had a ranking of 1 to 5 on movement lag being an issue where 1 is movement lag was not noticeable to 5 being movement lag was very distracting. The summary results of this section of the survey is included in Table 4.

TABLE 4: Usability and User Experience in Simulation

Question Pertaining to Usability	**Mean**	**Mode**	**Range**	**Stn. D**
Q5. User friendly navigation	1.42	1	1 to 2	0.493
Q6. Wayfinding: ability to your way around the model	1.40	1	1 to 2	0.490
Q7. Visual clarity of the model	1.92	2	1 to 3	0.560
Q8. Effects of movement lag on simulation experience	1.80	1	1 to 4	0.894

Overall user navigation and wayfinding through the simulation were identified as easy with a tight range (1-2) and a mode of 1 (very easy). The use of common controller-based navigation that the generation of student is familiar with and 93% indicating at least some level of exposure to video games allowed for an easy adoption to the navigation. This may not be the same with other generations or those who have not been exposed to controller-based gameplay. The simulation purposely used a simple model so it was not surprising to identify that wayfinding was also considered easy by the respondents. In a more complex model it is expected that wayfinding would be more of an issue.

The largest issue with visual clarity is the pixilation of the simulation when using a commodity headset because the headset is magnifying the pixels of the screen of the mobile device. It is understandable that the clarity can distract from the simulation and objects being presented which is why the question was asked. The findings indicate that clarity was not seen as an issue. Modelling was completed that allowed for material mapping and contrasts between elements to help identify depth of field and changes between elements of the model. This is a promising result since the use of a less expensive headset would allow for more headsets to be purchased by the department resulting in more students being exposed to the simulation content. Less expensive headsets also lead to the possibility for students purchasing their own equipment if enough content is made available to make it a sensible investment.

Movement lag was also addressed in the survey. Movement lag occurs when the simulation is too complex for the video processing power of the HMD. For portable HMDs, such as the Samsung GearVR and S7, processing power is limited compared to a tethered device so movement lag would be more likely to occur. Though there was a wider range of responses (1 to 4) the mode remained a 1 (that movement lag was not noticeable) with a mean of 1.80 on the 5 point scale. Models that are more complex with more surfaces to render would likely increase the amount of noticeable lag in processing and would likely result in a greater level of distraction to the user.

Open ended responses were used to document additional issues related to navigation and wayfinding through the model. These are summarized here:

- Navigation was easy to use and similar to that of video games respondent has played in the past, but noted that it may be difficult for those who have not played video games
- Pixilation of display identified as a potential issue depending on the details within the model
- Head tracking took some getting used to by several respondents

The third group of question dealt with user comfort, both physically and physiologically in terms of aspects of cyber sickness. For questions 9 through 11 the rankings were 1 for none at all and 5 to a great extent (enough to stop the simulation). For question 12 the rankings were 1 for not comfortable at all to 5 very comfortable. Question 13 asked about the weight of the device where 1 was comfortable (no different than where a pair of ski goggles) to 5 they were heavy and difficult to stay in place. Question 14 asked about their feeling of safety while using devices in front of others, a ranking of 1 was very comfortable and a ranking of 5 was very uncomfortable. The last question of the set (Q15) asked the student if the use of new technology, such as VR HMDs, for education caused them any anxiety. The responses were ranked as 1 none ("I'm comfortable with using new technologies"), 3 as unsure, and 5 as very much so. The results for this group of questions is summarized in Table 5.

TABLE 5: Comfort during Simulation

Question Pertaining to Comfort	Mean	Mode	Range	Stn. D
Q9. Nausea or queasiness during simulation	1.96	1	1 to 5	1.148
Q10. Feeling of eyestrain during simulation	1.52	1	1 to 3	0.574
Q11. Vertigo or difficulty maintaining balance	1.44	1	1 to 4	0.852
Q12. Comfort with occluded vision in front of others	4.32	5	3 to 5	0.733
Q13. Weight and stability of device	1.84	1	1 to 5	1.222
Q14. Feeling of safety while using device in front of others	4.04	5	2 to 5	1.280
Q15. Technology/VR HMDs for education cause anxiety	1.15	1	1 to 3	0.463

Nausea, eyestrain, and vertigo are all symptoms of cyber-sickness as previously noted. It is important to understand the effects of cybersickness on the population that would be using the technology. Though the ranges were high for Q9 (Nausea) and Q11 (Vertigo) the mode remained a 1 (did not experience any signs of…) and the means of 1.96 and 1.44 respectively do not indicate that these were a barrier in the study to more than a few respondents. Eyestrain (Q10) was not identified as an issue by any of the participants with a range of 1 to 3.

Respondents were given the option to provide comments related to the level of comfort they experienced throughout the simulation. Some of those comments are summarized and paraphrased below:

- Nausea feeling appeared more when moving head and controls at the same time.
- Felt eye-strain towards the end of the simulation
- Felt disoriented towards the end of the simulation
- Faster movements in the simulation gave a sense of unease/unbalance

In addition to the physiological discomforts, physical and psychological discomforts were examined. The weight and stability of the device (Q13) was not seen as an issue to most respondents. 12% rated the question a 4 or 5 meaning they had some issues with the HMD's weight or keeping it in place. Some of this could be placed on not having the head strap tight enough but if overtightened the strap can also place extra pressure on the users face around their eyes so a balance is needed. No one identified specifically why they felt it was uncomfortable. As far as psychological discomfort, there was a large range of students who had an issue with the idea of using the technology in front of a group of people and being the only one with their vision occluded. The mode was 5 (very uncomfortable) and a mean of 4.04.

6. COMPARATIVE ANALYSIS

6.1 Traditional Education Materials vs. HMD-VR

One of the purposes of the study was to see how students' perception of space, materials of construction, and components of assemblies change between the traditional learning materials of 2D images and the HMD-VR simulation. Survey 1 asked three questions about the renderings ability to convey the qualities of space, materials, and assemblies. The renderings were created from the model used for simulation and offered various inside and outside views of the model. Survey 2 asked the same questions but with using the simulation as the medium. Table 6 shows a summary of these responses and a delta mean.

TABLE 6: Ability of medium to convey information to users

	Survey 1			Survey 2			Delta
Question Topic	**Mean**	**Mode**	**Range**	**Mean**	**Mode**	**Range**	**Mean**
Q1. Spatial qualities and structural scale	3.89	4	2 to 5	4.72	5	4 to 5	+0.83
Q2. Materials used	3.85	3	2 to 5	4.72	5	4 to 5	+0.87
Q3. Components of wood frame construction	3.74	4	1 to 5	4.48	5	3 to 5	+0.74

All three areas improved from survey 1 to survey 2 with a higher mean, range, and mode. A comparison for each respondent's change in rating between the two mediums is shown in Fig. 4, 5, and 6. Fig. 4 shows the ability of the medium to allow for an understanding of spatial qualities of the structure. 32% of the respondents had stated no change in perception. 1 (4%) respondent indicated a better understanding with the Rendered Images. The remaining 64% indicated an improved understanding with Virtual Reality. 20% rated an improved understanding of spatial quality of 2 intervals moving from 3 with the rendered images to 5 with the VR. 1 respondent had an increased rating from 2 with the rendered images to 5 with the VR. The remaining had an increase of one interval between 3 and 4 or 4 and 5.

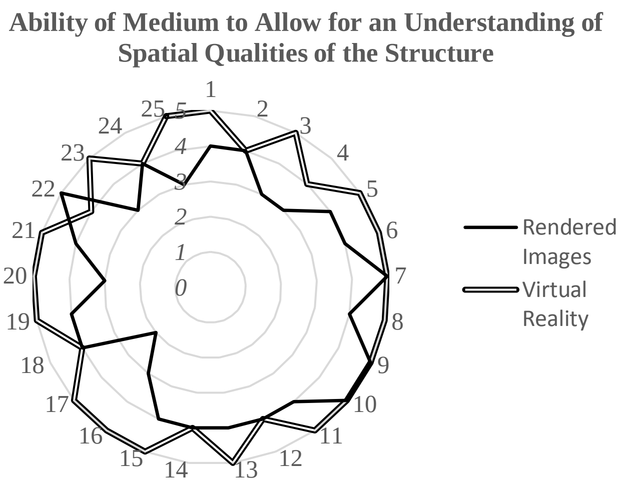

FIG. 4: Comparison of each respondent's ranking of "Spatial Quality"

The second question asked respondents about each medium's ability to allow for an understanding of components of construction (Fig. 5). 3 (12%) of the respondents indicated a higher ranking for the rendered images. 6 (24%) of the respondents did not indicate a change. 16 (64%) indicated an improvement in understanding the components of construction with VR. Of those that showed a preference for the rendered images there was a change in rating of 1 interval with VR being ranked at a 4 and the rendered images ranked at a 5. 8 of those who indicated a preference for the VR had an improvement of two intervals.

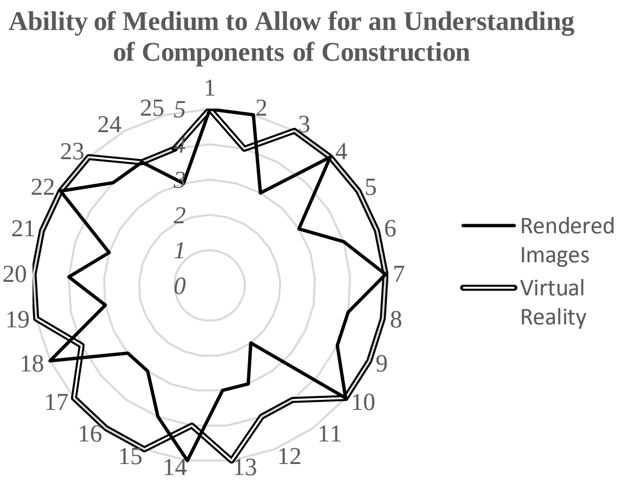

FIG. 5: Comparison of each respondent's ranking of "Understanding Components"

The final question that was asked comparing the two mediums of presentation on the ability of each medium to allow for an understanding of what materials were used (Fig. 6). 4 (16%) preferred the rendered images, 6 (24%) ranked the mediums the same, the remaining 15 (60%) ranked the virtual reality higher.

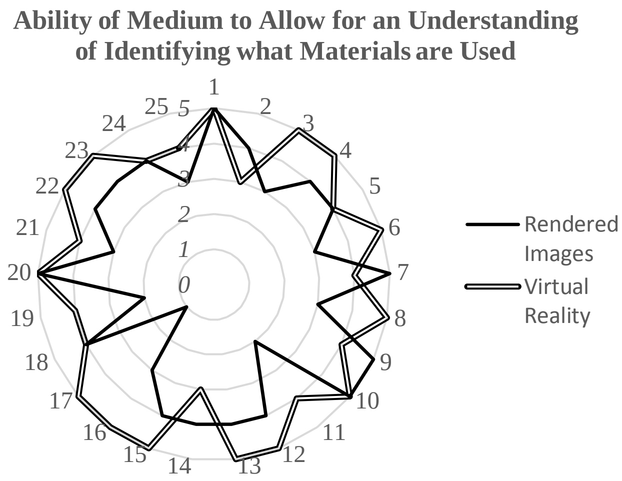

FIG. 6: Comparison of each respondent's ranking of "Understanding Materials"

These results were not overly surprising as other studies have shown the benefit of VR to visualize 3-dimensional space over 2-dimensional representations in architectural design students (Rahimian and Ibrahim, 2011) as well as other domains (Tanagho, et.al, 2012) so the use of HMD-VR should provide for better spatial understanding.

6.2 Effects of Prior VR Use and Video Game Use

A correlation analysis was completed based on the various use of VR and amount of console controller-based video game use and their effects on the usability factors (Table 7). Prior VR usage has a weak correlation to navigation and wayfinding. This could be because the prior VR use was not defined into type of use, but simply that the respondent had exposure to it before. In the open responses for those who had prior use of VR, 50% used it for a video game the other 50% used it for some form of visualization (video, walk-through of a home, etc.). The largest influence on wayfinding was the prior use of video console controller-based video games. The negative correlation shows that there is a slight relationship between the amount of time spent playing video games and the ease at which users can navigate the environment. Those who had no video game use or only some video game use had a more difficult time with wayfinding. However, it is worth noting that no one indicated that wayfinding was hard or very difficult and the mean on a 1-5 scale was 1.38.

TABLE 7: Correlation Analysis of Demographic Status to Model Usability Factors

Question	Mean	Stn D	Prior VR Use r	Video Game Use r
Q5. Navigation	1.40	0.4899	0.3611 (weak)	-0.1549 (none)
Q6. Wayfinding	1.38	0.4865	0.3611 (weak)	-0.3336 (weak)
Q7. Visual Clarity	1.92	0.5493	0.0421 (none)	0.2564 (very weak)

A second correlation analysis was conducted to identify effects of prior VR use and amount of video game exposure on factors of discomfort that include Q9. Nausea/Queasiness, Q10. Eye Strain and Q11. Vertigo/Issues Maintaining Balance (Table 8). The only statistically significant correlation is prior usage of VR having a positive correlation to the amount of vertigo/balance. This would complement prior findings of Kennedy et.al. (2000) that more sessions of exposure allow to brain to adapt to conflicting stimuli and reduce the effects of cyber-sickness. Secondarily, in the same issue of vertigo the extent of video game exposure has a very weak negative correlation. It is possible that those who play more video games are better adjusted to the visual stimuli of those video games and that the level of immersion does not have as much affect as others so they have less vertigo and issues with balance. There may also be other factors that were not part of the study that influence these results as this is a statistically weak correlation.

TABLE 8. Correlation Analysis of Demographic Status to User Discomfort

Question	Mean	Stn D	Prior VR Use r	Video Game Use r
(9) Nausea	1.92	1.1410	0.1181 (none)	-0.0264 (none)
(10) Eye Strain	1.50	0.5718	0.2465 (very weak)	-0.1770 (none)
(11) Vertigo/Balance	1.42	0.8400	0.5397 (moderate)	-0.2931 (weak)

7. FUTURE CONTENT DEVELOPMENT AND TESTING

Concerning simulated environments, students provided input on an initial study (Lucas, 2018) that suggested the use of the simulation for visualization of building assemblies and construction sequences is the largest perceived area of benefit by the students. This couples well with the needs observed in the classroom that sequencing of construction in Materials and Methods, Estimating, and Scheduling is a week area for most students. If the visualizations can be produced, they can help supplement hands-on experience that usually help the students grow a better understanding of how things are actually built and sequenced during construction.

The new simulations that represent construction sequencing of various assemblies and tasks are under development. The new simulations consist of a user examining construction assemblies at various stages of construction to understand the sequence of construction (Fig. 7). Various classes will utilize the simulation and provide student feedback on the simulation's development. Studies will be completed to identify learning gain advantages/disadvantages of using the simulation and to also identify the student perceptions and reactions.

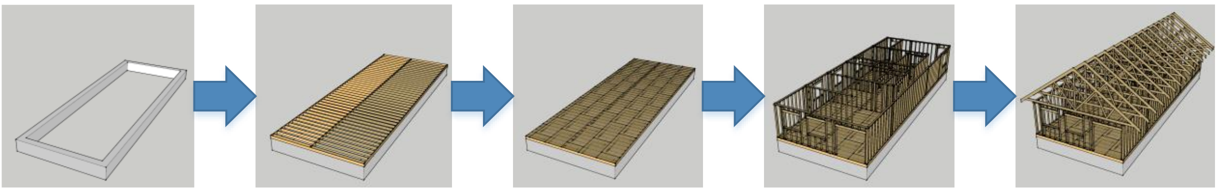

FIG. 7: Construction Assembly and Sequence Simulation

When simulations are created for one medium, Unity allows for easily building it for other platforms. This will allow for wide-spread dissemination of desktop computer based simulations for students to install on their own computer. Comparisons studies can then be done that compares student performance for those who use the desktop version and those who utilize the immersive HMD-VR simulation. Virtual simulations and educational games have already been identified as beneficial for promoting learning so differences between a desktop and immersive simulation on learning can be identified.

In addition to simulated environments, the use of 360-degree video is also being explored as a way to bring the site to the students. Site visits take up time for coordination and travel which minimizes the available number of site visits that take place in any given class throughout a semester. However, since site visits are so valuable to the student's education, 360 degree video is being explored as a method to bring the site to them. Construction activities will be videoed in 360 degree video format and have basic information overlaid at appropriate points of the video. The student will be able to control the speed of the video as well as replay the video to monitor construction processes. Placing this in an immersive environment will allow the student to understand scale and allow them a sense of presence within the space while the construction activities are occurring.

Additional studies will be completed to compare the video simulations versus the computer-generated simulations. One immediately known limitation to the video simulation is the user will only have head-tracking motion control because the video will be produced from stationary and fixed positions. Student feedback and summative testing will be conducted to identify the benefits of each method. The results will guide the direction of future learning content development.

8. DISCUSSION

The first concern as mentioned earlier is the feeling of cybersickness. It is important to allow students to use the technology only to the point that they are comfortable, realizing that some students will feel discomfort fairly quickly. Consideration has to be given to the duration of immersive learning modules as most studies identify longer exposure as putting the user at greater risk for feeling discomfort (Cobb et.al, 1999; Regan and Price 1994). Since Davis et.al. (2015) hypothesize that cybersickness is increased with the realism of the environment; an animated model of discernable components as opposed to photorealistic renderings may be beneficial and should be explored. Since HMDs powered by mobile devices are being used in the research the models also need to be within a size that allows for them to be processed smoothly. Increased movement lag within the modeled environment can lead to contradictory stimuli and more cybersickness.

Another concern is the user's comfort. Physical comfort did not appear to be an issue with the first study. Only a few students had an issue of keeping the HMD in position and adjusting the straps could have helped with the stability of the HMD. A higher concern is psychological comfort in terms of feeling safe while in a space and having your vision occluded. It is important to understand that this can cause comfort issues and may prevent some students from fully taking advantage of the technology in the classroom. For that reason, outs-side of class availability and use of the technology may be beneficial so students can use the technology in private and not have the concern of others observing their use of the technology.

9. CONCLUSIONS

This study developed an immersive HMD VR simulation that allowed students to explore a model of a house that was under construction and at the framing stage. The intention of the simulation was to allow students to freely navigate through the environment and observe the features of the construction. As a result, the students were surveyed and asked where they could see this technology being used, what level of physiological, psychological, and physical discomfort exists, and how well does the simulation convey features of the construction.

The preliminary results show a slight increase in understanding of space and other features of the model when using VR as opposed to looking at rendered images that represent traditional learning materials. The most benefit identified was understanding components of construction within the HMD simulation. This was a shared sentiment with open responses that suggested the use of VR for sequence and assembly of construction components to support Estimating, Scheduling, and Materials and Methods would be the most beneficial use of the technology in terms of enhancing the curriculum. The students responded very positively to the use of the HMD simulations and its potential for use in the classroom. Most of the traditional student generation currently at the university had indicated some level of use of prior video game use however even those who had minimal or no console based video use did not have significant issues with navigation and controls. Responses were that they were quite natural and not difficult to learn.

Physiological discomfort in terms of eyestrain, vertigo, and nausea was minimal according to student self-identified responses. The psychological comfort of the user when using the technology in front of other people while having their own vision occluded was of larger concern. This would need to be taken into consideration with future availability of the technology and where and when students have access to it.

Overall, the results of this first study were positive and highlighted some areas where simulations can be developed to further enhance the education curriculum. Future research will explore computer generated simulations and 360 recorded video as options for immersive virtual environment simulation. Various levels of interaction need to be tested to see what is the most beneficial. Appropriate text, sound, and video additions to the simulations can increase the perception and learning within the environment. With the technology becoming more cost effective, it is conceivable that every student in the classroom could own a mobile HMD that works with their cellphone and the simulations can be a commonplace supplement to standard course text.

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