ASEE 2022 ANNUAL CONFERENCE
Excellence Through Diversity
MINNEAPOLIS, MINNESOTA, JUNE 26TH-29TH, 2022 ASEE

Paper ID #37724

Enhanced Learning of Load Path in a 3D Structural System using Virtual Reality

Juan Andres Torres

Juan is a master’s student in Sustainable and Resilient Infrastructure Systems. He obtained his Bachelor of Science in Civil Engineering at Universidad San Francisco de Quito, Ecuador in 2019. He has research experience in Structural Engineering in the field of Steel Fiber Reinforced Concrete. His current research interests lie in the use of virtual reality for education in civil engineering, structural health monitoring and innovative structural systems.

Ann C Sychterz (Assistant Professor)

I obtained by PhD in 2018 from the Swiss Federal Institute of Technology Lausanne (EPFL) addressing the novel use of control algorithms, statistical diagnostic tools, and real-time feedback on a full-scale tensegrity structure to enable smooth deployability, damage detection, adaptation, and learning (https://youtu.be/FeXxjerleZE). During my masters of applied science obtained in 2014 at the University of Waterloo (UW), I built full-scale aluminum pedestrian bridges for vibration characterization and control. I completed my bachelor of applied science in civil engineering at the University of Waterloo in 2012. Before coming to the University of Illinois, I completed a postdoctoral position at the University of Michigan through the successful Swiss National Science Foundation Early.Postdoc Mobility grant that I authored on the actuator optimization of adaptive origami structures. My research work is focused on designing, building, testing, and simulating of structures that are adaptive, lightweight, large-scale, resilient, and sustainable.

Jacob Henschen (Teaching Assistant Prrofessor)

Jacob Henschen is a teaching assistant professor at the University of Illinois at Urbana-Champaign in the Civil and Environmental Engineering Department. He received his B.S., M.S., and Ph.D. from the University of Illinois at Urbana-Champaign. His research interests include additive manufacturing with cementitious materials and the use of virtual reality in undergraduate education.

Enhanced Learning of Load Path in a 3D Structural System using Virtual Reality

Introduction

Virtual reality (VR) has evolved from being used only in video-games to be used as a powerful educational tool in the areas of engineering education. It us useful due to its ability to recreate the real world in a costly efficient manner [1]. Research [2, 3, 4] has shown that the use of VR in engineering education has improved the learning process and increased the motivation of students of understanding new concepts, developing a better ability to visualize a design and improving spatial skills. These skills are essential for engineering understating and judgment during professional development [5]. Furthermore, Wu et al [6], who studied the use of augmented reality, similar to VR, can enhance the student's sense of presence, immediacy and immersion to have a better engagement. Additionally, it can provide a ubiquitous, collaborative and situated learning for a better notion of contextualization, as well as providing learning content in 3D perspectives where they can visualize what is not obvious, hence, gives a sense of authenticity [6]. A review of the uses of VR in engineering education [7] suggests that for evaluating the use of VR as a teaching tool the metrics should be well defined together with a formal and rigorous evaluation on the learning outcomes. Dinis et al [8] analyzed the learning outcomes in the learning process with the use of VR as teaching tool finding that a game-based interface can motivate students during this process. Some researchers [9, 10] emphasize the advantage of the low cost in the use of VR not only in education but also in the construction industry. However, McCabe and McPolon [9] suggest that the VR app should be modeled in a way that the user feels more comfortable to interact in this immersive virtual space.

The feasibility of using VR as a teaching tool in engineering is investigated based upon how comfortable the students feel when trying this technology. A qualitative study was carried out through surveys to measure and analyze the viability of using VR to teach concepts such as load path. As shown in Figure 1, this paper presents results from the first phase of a broader research initiative whose objective is to conduct a comparative study of the traditional method of using 2D drawings with the use of a VR representation of a building in the learning outcomes, specifically, in the understanding of the concept of load path.

Engineers and architects use 2D drawings to create 3D structures. In the last decades, CAD drafting has been the main tool to create drawings and it is the current standard in construction and design as well as in teaching. However, in the last years, BIM technology has been playing an important role in the construction field since it gathers a broader range of useful information related to the projects[11, 12]. Azhar et al [13] provide with a list of benefits of the use of BIM not only in industry but also for future professionals. The main difference between CAD and BIM is that BIM models buildings consider a wider variety of information including the form, function, and behaviour of building systems and components [14]. This transition is also happening in education with the use of BIM to create VR models. Even though VR headsets seem expensive, they represent a relatively low-cost option compared to the different 2D drafting software licenses. Moreover, it does not represent a high risk due to high contact when regular safety measures are used such as cleaning the headset with 80% isopropyl alcohol before and after each use. Setareh et al [15], developed a VR application to analyze building structures as a tool for students and professionals in the construction field to have a better understanding of the structural behavior. Nonetheless, students often struggle with this transition from 2D drawings to 3D models and vice-versa, as a result, it is complicated to develop the skill of translating 2D drawings into 3D models. Furthermore, the tracking of the flow of forces from structural member to member becomes a related issue on this matter. This problem is accentuated in higher level courses where system-level design is studied. For instance, in structural integrative design (SID) courses, which are senior-level course that combines steel and concrete design together with ASCE 7-22 Standard provisions for minimum design loads [16]. For our research we selected one of this courses to conduct our qualitative study. In such course, students are required to design the structural system of a building as a project. The concepts learned during this class are fundamental part of the education of a civil engineer. One of the expected outcomes is that the students develop the ability to understand how the different structural members carry the different loads acting on the structure, called the load path [17].

In the present research, we study the feasibility of using a VR interactive environment to teach the concept of load path in such type of courses. For this purpose, a VR representation of an existing building was developed in Unity, which is a gaming engine used to create 3D games supported in VR. An Autodesk Revit model of an existing building was imported into unity with the use of a plugin that allows exportation from Revit to Unity. The modeled building is the Campus Instructional Facility located in the campus of the University of Illinois Urbana Champaign. The designer engineers of the building shared the structural and architectural drawings for educational purposes. A qualitative study to analyze the comfortability was conducted in groups of students from the selected class who tried the VR app, several questions regarding to previous use of VR, easiness of use and setup, level of comfort, easiness on navigation, and quality of rendering. This is done to take a decision of continuing with the research or updating and improving the VR app to provide a more comfortable feeling to the students for using it as a teaching tool. It is important to recall that the student from the selected class are in their senior year, hence, the information presented is not new content for them but it is presented using a new modality (i.e. virtual reality). The present research contributes to the field of engineering education by providing with a new tool and methodology to address the issue of learning the load path concept. A different approach perspective is studied by using 3D models instead of the traditional 2D drawings.

This ongoing research addresses the difficulty of understanding concepts of structural systems by providing students with a different teaching and learning approach with the use of the technology of VR. The proposed approach is to import a Revit model into Unity and create a VR model that can be used as a teaching tool. This VR model was tested for adequacy in a course of civil engineering to conduct a qualitative assessment on the comfortability on the use of VR. It is expected that the use of 3D visualization of structural and architectural details in virtual reality brings a better ability to describe load paths due to the immersive experience of being inside a building and interact with the different structural elements.

Methodology

The flowchart of the methodology used for this research is shown in Figure 1. As seen, the first step (i) was the selection of the building from which a VR model was going to be created, for the present paper we used the Campus Instructional Facility building, further in this paper some details and specifications of the building are explained as well as the reason for selecting this building. The second step (ii) was to create a Revit model of the building, in this case, a previous model was retrieved and adjusted to meet our interests. The next step (iii) was to select a location for observation in the building, which is called the region of interest, we chose an open area where several structural and architectural details can be noted easily. The following step (v) was to model the connection's details according to as-built conditions. For the present project, the connections were modeled in Tekla, a BIM software used in the construction industry, and then reimported into REVIT. However, such connections can also be modeled in REVIT.

Once the final 3D model was ready it was imported into unity using a plugin (vi). This process is detailed later in this section. Following, the 3D model was imported into Unity (vii), an *.apk package containing the model was created in order to upload it to the VR headset (viii). The *.apk package allows the model to be launched in the headset. In this case we used an Oculus Quest 2 headset [18] and we uploaded the *.apk package using the software Sidequest. This headset is, at the present time, the lowest standalone wireless VR headset commercially available.

Next, we divided the class in groups of 3 people to make an assessment on the comfortability with the use of the app (ix). It is necessary to divide the class in smaller groups depending on the headset availability. Groups ranging from 3 to 5 people are recommended to share the headset among them. It is important to mention that the time of use is in average 5 minutes per person. This period of time is enough to navigate through the model and use the different features of the VR app. The main goal of this paper is to analyze the feedback in students comfort using the VR app to decide if it is adequate and the research can continue to the following steps or if there are adjustments to be done to the app before continuing with the research (x). This was done by conducting a qualitative survey to asses the comfort level with VR in students. The students feedback was analyzed and from the results obtained it was shown that the app was comfortable and adequate to continue with the research.

The first step of the second phase (xii) of the broader research initiative is to develop a graphical overlay in the VR app that helps in the learning and teaching of the load path concept, this graphical overlay will be composed of moment, shear, and bending diagrams in the different structural members together with the load path that shows the flow of forces carried by such elements. This graphical overlay will be added to the VR app and then will be used for making a comparative study between the learning outcomes from 2D drawings and VR app. As shown in step thirteen (xiii), the class will be divided into 10 groups of even numbers depending on the availability of headsets. Half of the groups will begin learning the load path concept with the traditional method using 2D drawings, the other half will begin learning the concept using the VR app. Afterwards, each student will be tested on this concept using a different building from the CIF. After the test, the groups who started with 2D drawings will use the VR app and vice versa. Then the students will take a test again. This is shown in steps (xv) to (xviii). Following, data results will be collected (xix) and processed (xx), and results will be analyzed in a quantitative comparative study for which the expected outcome is to characterize the percentage improvement in scores due to the use of the VR app (xxi).

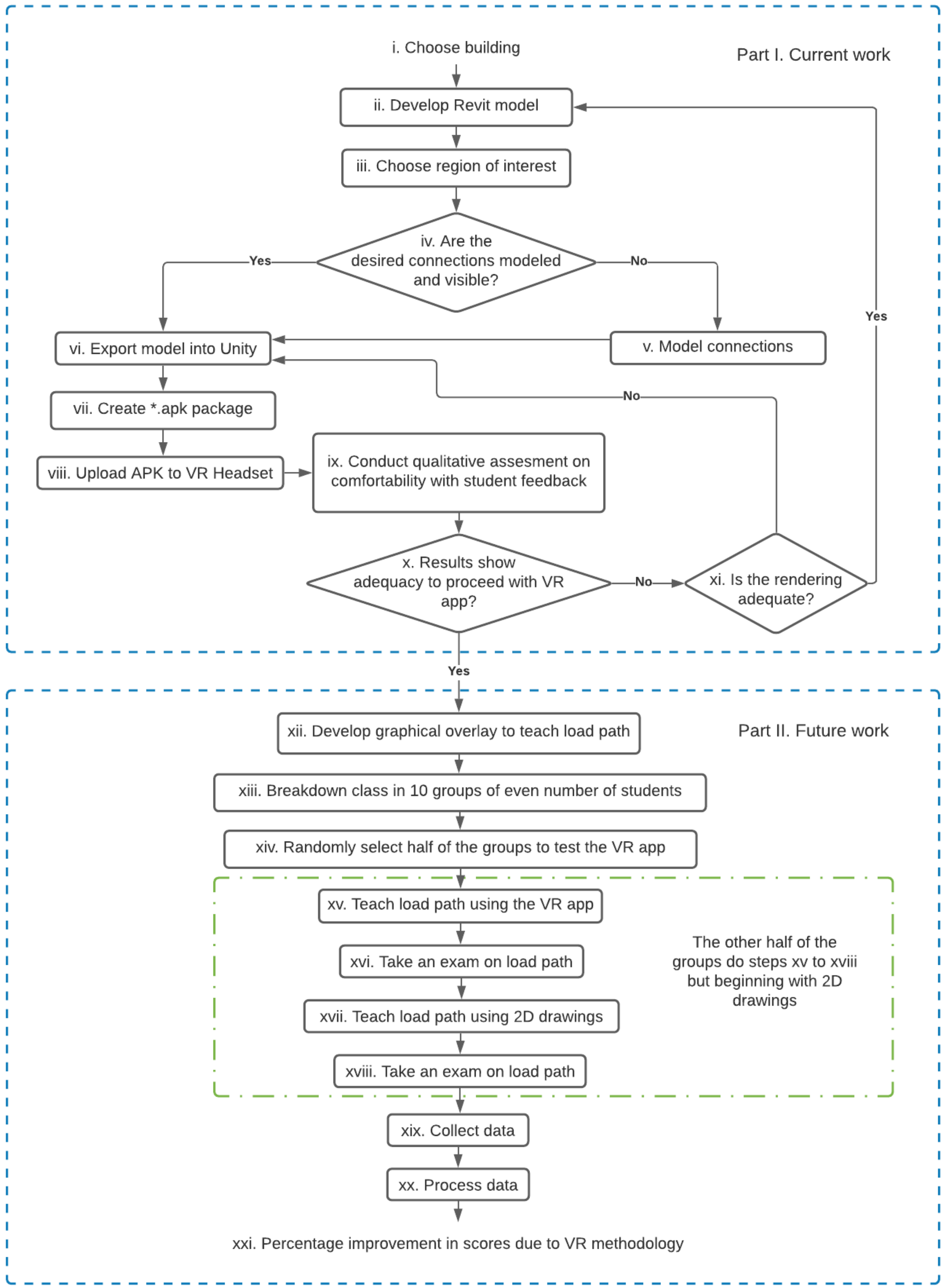
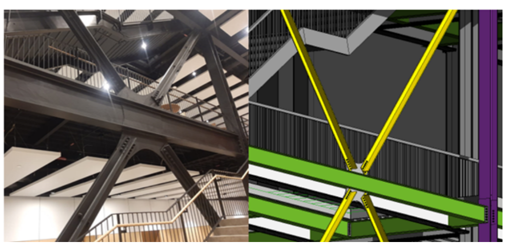


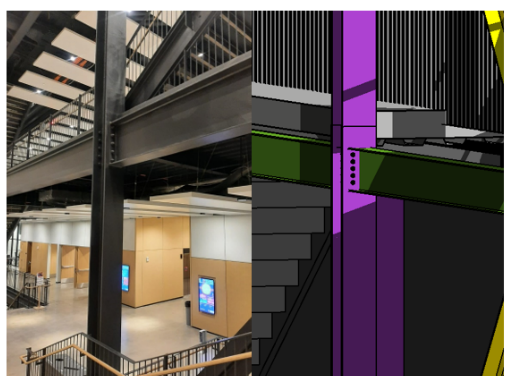
Figure 1: Flowchart of Research

Figure 2 shows a group of pictures of the selected building, the Campus Instructional Facility (CIF), together with their respective 3D model. This building features an exposed steel structure which highlights the load path as seen in the detail of the gusset plates (a) for which engineering optimization was done, instead of using the traditional rectangular gusset plates, curved plates that follow the load acting on the braces were used, this feature also allows the architecture to be integrated together with the structure in a smooth way. All braces of the building (b) use a double T section bolted to the optimized gusset plates. In addition, the different connections can be seen for the majority of elements as shown in the beam-column connection (c) which is a bolted moment connection using end plates, most of the connections between girders are shear connections except in spots where a moment connection is needed. This VR methodology could be used by any faculty who has a Revit model of a building they would like to visualize in VR. The time may depend on the level of detail required in the VR. If the level of detail is the same as the Revit model, this process would take no more than one week to implement for a new building.



(a)

(b)

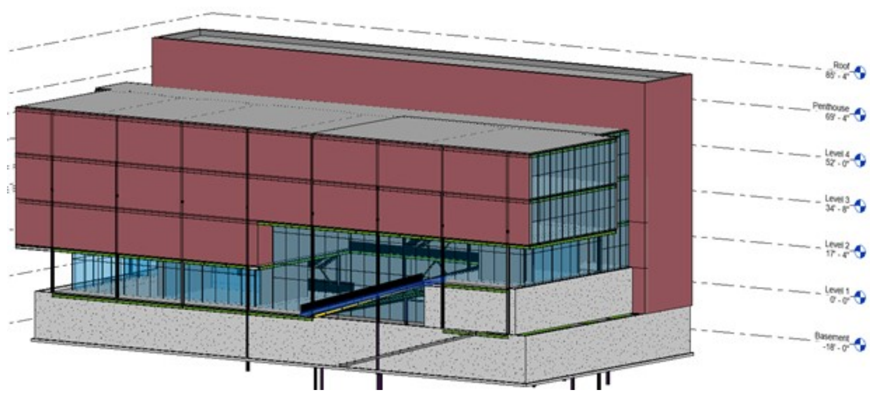


(c)

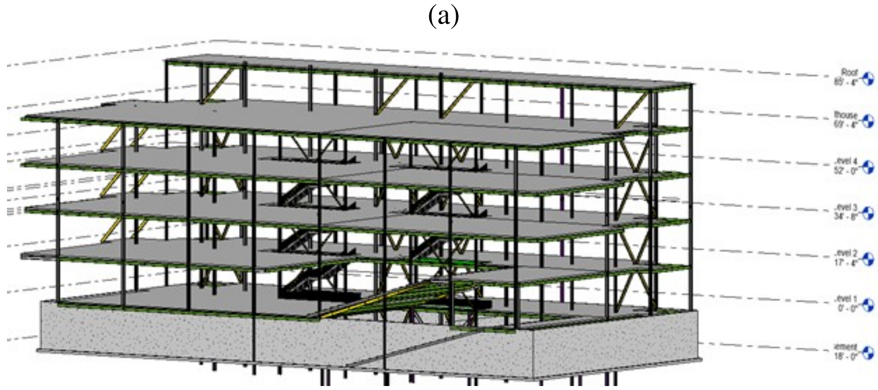
Figure 2: Pictures of the CIF (a) gusset plates (b) braces (c) beam-column connection

Traditionally, 2D drawings are used to teach the concept of load path as well to understand the structural distribution of a building. Plan views and an elevation views are provided to the students to analyze the different loads carried by the different structural members in each floor and the cumulative load carried by the columns, as well as the lateral load taken by the braces. This is done by analyzing which type of load is being carried in the different areas of the building according to the type of occupancy in such areas. Additionally, the students learn how the loads are distributed and carried by the different structural members. Moreover, information regarding length and spacing of the members can be retrieved from these drawings. This is important for the second phase of our research which is focused on teaching the load path concept with the use of VR.

In the past decade, there has been a transition from 2D drawings to 3D BIM models to coordinate the fields of architecture, structural engineering, civil engineering, mechanical electrical and plumbing, as well as geotechnical engineering. This can be seen in Figure 3 which shows the architectural and structural 3D models of the CIF building. The developed VR app has a toggle tool that allows the user to switch between these two models, this is a very helpful tool since all the architectural details (e.g. facade, dry walls) can be removed which can be complicated in 2D drawings. This will allow students to have a better visualization and it is expected that this will help them to understand which architectural details are carried by which structural members.



(a)



(b)

Figure 3: Perspective view of 3D models (a) architectural model (b) structural model

After the model in Revit is ready it has to be imported into Unity, which is a gaming engine used to create virtual reality environments. For the purposes of this research the plugin Direct Link™ was used because it allows importation from Revit to Unity. It is important to mention that at the date of this paper this plugin only works for Revit 2021. Figure 4 shows a snapshot of the model in Unity. Unity provides many tools that are useful to create a VR environment that looks very similar to reality together with the Revit model, during this step of the process rendering and lighting adjustments are done to the model in order to have an easy navigation when used in the headset. In addition, the starting point of the camera in the scene is selected. Furthermore, structural and architectural model were located in the same place for the user to have the option to toggle between them. Finally the model is packaged as an *.apk file for the VR app to be uploaded in the headset. Several adjustments were done previously both in the Revit and in the Unity model to have the final version of the app to be tested in the students.

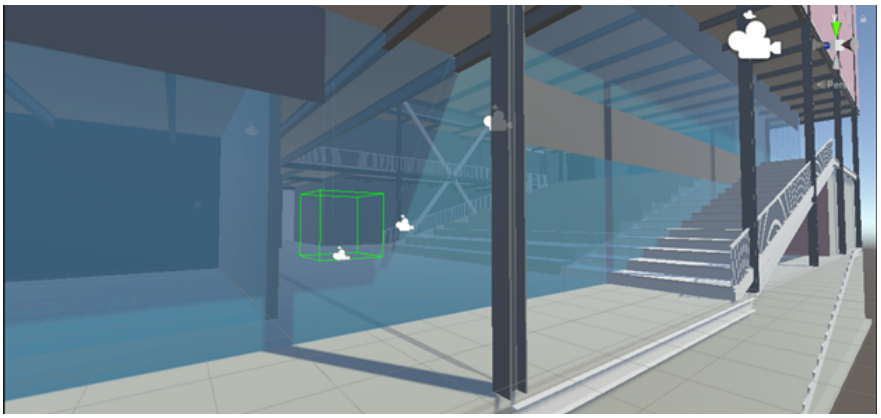
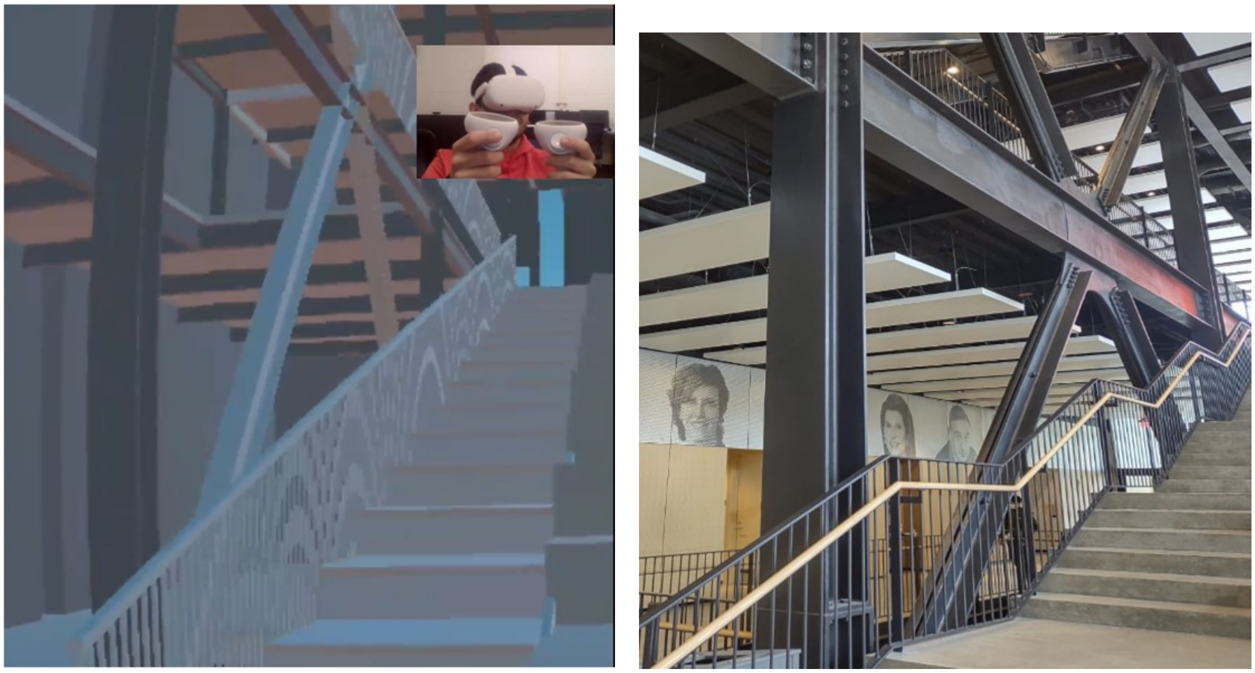


Figure 4: Model in Unity

The streaming of the VR app and the actual location of this area are shown in Figure 5. The VR app can provide with a very similar visualization of the reality, and it is expected that this allows students to have a better comprehension of the different concepts taught in civil engineering courses. This is an alternative to taking the students to walk around the actual building which is a good option for example when a building is located in a different city or for students who are not able to go to the location. It also offers an advantage when some of the structural members are not accessible. The model also provides with the advantage of switching between the structural and architectural model which is helpful to have a better comprehension of the structural distribution since in the majority of buildings such structure is hidden by architecture details.



(a) (b)

Figure 5: Streaming of VR App (a) streaming of VR app (b) location at point of streaming

Once the VR model was adjusted for the different requirements for our purpose, a questionnaire was created to analyze qualitatively and decide if the VR model is adequate and comfortable to be used as a teaching tool in an engineering course. This survey containing 7 questions was conducted in a group of 19 students from the selected class during the third week of classes of the spring 2022 semester, a picture of the testing is shown in Figure 6. The students navigated through the VR simulation for approximately five to ten minutes and then answered the qualitative survey. Survey questions are presented in Table 1. First, previous experience with VR was investigated. The following questions addressed the issue of comfortability with the setup, use and navigation of the developed VR app. Another question addressed the preference of students between using VR or walking through the building. Finally, a comparative question was asked regarding the comprehension of structural distribution between 2D drawings and the VR model, this was done by providing them with the 2D drawings of the building one week earlier from the VR testing and have them analyzed in this subject, later they navigated through the model to provide an answer for this question.

Table 1: Survey questions and rationale

No.	Question	Rationale
1	Have you ever used virtual reality in the past?	To asses the previous use of VR in students and to find out what do they use it for
2	If you answered yes in question 1, for how long do you often use it?	To assess how long they are used to use their VR headsets and define what is a comfortable time of use
3	How comfortable do you feel using virtual reality?	To asses the general experience with the use of VR app
4	How comfortable did you find yourself putting on and setting up the VR headset?	To assess the easiness of wearing the headset and using its controls
5	How comfortable did you feel when moving and navigating through the model?	To assess how the VR app is perceived by the students and find if there is some adjustment that needs to be made
6	Which of the following do you prefer: a) Walk through the building in the real life or b) See the virtual reality model of the building	To determine if the VR simulation can replace the actual experience of going to the building
7	Which method gave you a better comprehension of the structural distribution of the building? a) 2D Drawings b) 3D VR model	To asses if the immersive experience of VR provides a better understanding of spatial distribution

Figure 6: Students testing VR app (consent for photography was given by students)

Results

The results of the first four question of the survey are shown in Figure 8. For the question regarding the use of VR in the past (a), several options were given, however only two of them were an answer, most of the students (53%) had never used VR before, the remaining 47% had used it only to play videogames. From this 47% of students who had previously used VR technology, 89% had used it for the period of time from 0 to 1 hour, only the 11% had used it for 1 to 5 hours, none of these students had used VR for more than 5 hours as shown in (b). For the question that asked the student preference between walking through the building or see the VR model of the building, shown in (c), a vast majority of 95% of students would prefer to walk through the building compared to a 5% that prefer to see the VR model of it. Finally, in the comparative question of which method provided a better comprehension of structural distribution of the building (d), 79% of the students answered that the VR model provided a better comprehension compared to 21% that answered that they had a better comprehension from the 2D drawings.

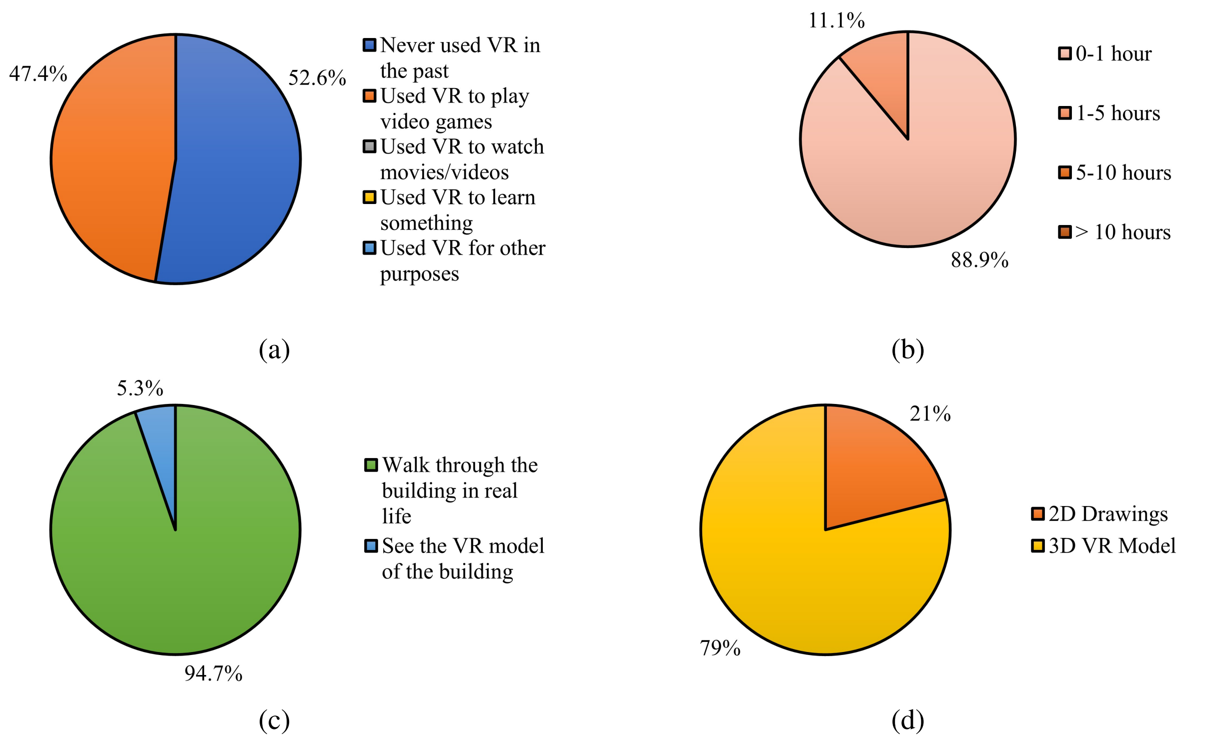


Figure 7: Results of survey (a) previous use of VR (b) time of use for previous VR users (c) preference of students (d) better comprehension of structural distribution

Results of the questions regarding the comfort level are shown in Figure 8. For the general use of VR, 26% of the students felt very comfortable, 32% felt comfortable or neutral, 10% felt uncomfortable and none o the students felt very uncomfortable. Results of the putting on and setting up the VR headset show that 32% felt very comfortable doing this, the majority of students with a 47% felt comfortable, and the remaining 21% felt neutral, none of the students felt neither very comfortable nor very uncomfortable in this process. Finally, the survey results for the navigation through the model showed that a 10% of the students felt very comfortable, most of the students with a 53% felt comfortable, while 32% felt neutral and 5% felt uncomfortable.

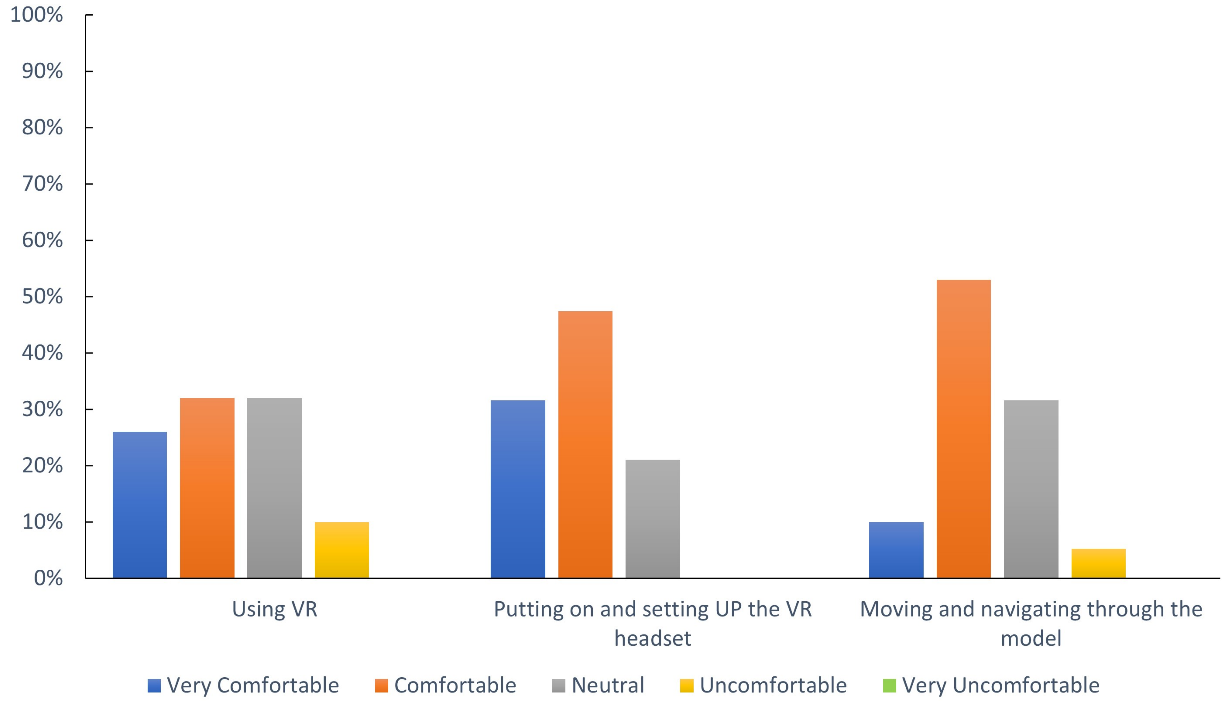


Figure 8: Comfort level in the use of VR

Discussion

The results obtained from the previous use of VR show that it is not common that students who use VR use it for a different reason to play videogames, this plays a fundamental role in our research because from the perspective of a student it might be difficult to see the VR technology as an educational tool. However, during the testing, students seemed eager to use the VR and also enjoyed trying the VR app.Additionally, the results show that a period of use of more than one hour is not practical since the majority of students that had used VR in the past often use it for less than one hour.

A great majority of students would prefer walking through the building in real life than watching it in a 3D VR model, this could indicate two things: the model needs improvement to be compared to the real life model or that nothing can actually be compared to the experience of being in the building itself even if the most detailed model was used. A detailed survey of this should be carried to find which is the real cause of this preference. We can also debate this by stating that the students are comparing their experience to what they can actually see in the building, but this is complicated when some of the structural elements are not reachable or are hidden behind the architectural details. From the comparative question results, we can infer that using this 3D VR model improves in a great way the comprehension of structural distribution compared to the traditional 2D drawings which were provided to the students two weeks before the VR testing was conducted. Comprehension of structural distributions is referred to the concern that students would identify the location of different structural elements such as beams, columns, and braces. This is significant because, regardless of the short time of use of the VR app, they have a better understanding of the technical subject. This is significant because, regardless of the short time of use of the VR app, the have a better understanding of the technical subject. This demonstrates and emphasizes what other researchers has shown before and provide us with the feedback that using VR for teaching is a good tool that improves spatial skills in the students. The findings do not explicitly indicate that the VR experience improves the skill of interpreting 2D drawings. However, as spatial abilities are enhanced, it is expected that the skill of understanding 2D drawings will be enhanced as well. Thus, VR methodology would serve as a complement to 2D drawing interpretation.

The results of the survey show that the VR app shows that for the group of students interviewed there is a general comfort using the VR app; a minimal fraction of the students felt uncomfortable, a more detailed survey should be done to understand the causes of such discomfort. A general comfort was found in the issue of setting up of the VR headset, this infers that using such headset in a classroom would not be difficult and the students can easily get along with it. The question with the greatest weight for our research is the one regarding the movement and navigation through the VR model, a general accepted comfortability was found in this case, except for one person who found the model uncomfortable. From the obtained answers we can infer that there is an adequacy for the VR model to be used as a teaching tool in engineering courses. The results obtained in this study show the use of VR as a promising tool for teaching engineering concepts which also offers a more enjoyable learning environment. However, a survey focused on what can be improved or upgraded should be carried for understanding the expectations of the students and provide with a better product.

Conclusions

In the present research, we studied the feasibility of using a VR interactive environment as a teaching tool for civil engineering courses. A VR app was created and a group of students provided their feedback through a qualitative survey after they tried the VR app. The results show a promising future for this tool as the majority of the students felt comfortable during their experience. However, some challenges need to be addressed to provide a more similar to reality environment.

References

[1] K. M. Chuah, C. J. Chen, and C. S. Teh, “Incorporating kansei engineering in instructional design: Designing virtual reality based learning environments from a novel perspective,” *THEMES IN SCIENCE AND TECHNOLOGY EDUCATION*, vol. 1, no. 1, pp. 37–48, 2008.

[2] S. Alizadehsalehi, A. Hadavi, and J. C. Huang, "Virtual reality for design and construction education environment," *Integrated Building Solutions - The National Agenda - Proceedings of the Architectural Engineering National Conference*, pp. 193–203, 2019.

[3] F. M. Dinis, A. S. Guimaraes, B. R. Carvalho, and J. P. P. Martins, "Virtual and augmented reality game-based applications to civil engineering education," *2017 IEEE Global Engineering Education Conference*, pp. 1195–1202, 2017.

[4] B. Y. Belgacem and B. Berry, "Learning to think spatially in an undergraduate interdisciplinary computational design context: A case study," *International Journal of Technology and Design Education*, vol. 22, no. 4, pp. 541–564, 2012.

[5] J. L. Mohler, "Examining the spatial ability phenomenon from the student's perspective," *Engineering Graphics Design Journal*, vol. 72, no. 3, pp. 1–15, 2008.

[6] H.-K. Wu, S. W.-Y. Lee, H.-Y. Chang, and J.-C. Liang, "Current status, opportunities and challenges of augmented reality in education," *Computers and Education*, vol. 62, pp. 41–49, 2013.

[7] J. di Lanzo, A. Valentine, F. Sohel, A. Yapp, K. Muparadzi, and M. Abdhelmalek, "A review of the uses of virtual reality in engineering education," *Computer Applications in Engineering Education*, vol. 28, no. 3, pp. 748–763, 2020.

[8] F. M. Dinis, A. S. Guimarães, B. R. Carvalho, and J. P. Poças Martins, "Virtual and augmented reality game-based applications to civil engineering education," in *2017 IEEE Global Engineering Education Conference (EDUCON)*, 2017, pp. 1683–1688.

[9] A. McCabe and D. McPolin, "Virtual reality: immersed in the structural world," *The Structural Engineer*, vol. 93, no. 3, pp. 20–23, Mar. 2015.

[10] O. Halabi, "Immersive virtual reality to enforce teaching in engineering education," *Multimed Tools Appl*, vol. 79, pp. 2987–3004, 2020.

[11] G. O. Deniz, "Emerging cad and bim trends in the aec education: An analysis from students' perspective," *College of Architecture and the Built Environment Faculty Papers*, 2018.

[12] L. Wang and F. Leite, "Process-oriented approach of teaching building information modeling in construction management," *Journal of Professional Issues in Engineering Education and Practice*, vol. 140, p. 04014004, 10 2014.

[13] S. Azhar, M. Hein, and B. Sketo, "Building information modeling (bim) : Benefits , risks and challenges," 2008.

[14] R. Sacks and R. Barak, "Teaching building information modeling as an integral part of freshman year civil engineering education," *Journal of Professional Issues in Engineering Education and Practice - J PROF ISSUE ENG EDUC PRACT*, vol. 136, 01 2010.

[15] M. Setareh, D. A. Bowman, and A. Kalita, "Development of a virtual reality structural analysis system," *Journal of Architectural Engineering*, vol. 11, no. 4, pp. 156–164, 2005.

[16] *Minimum Design Loads for Buildings and Other Structures*, ASCE/SEI 7-22 ed. American Society of Civil Engineers, 2021.

[17] D. Kelly, P. Hsu, and M. Asudullah, "Load paths and load flow in finite element analysis," *Engineering Computations*, vol. 18, no. 1/2, pp. 304–313, 2001.

[18] Facebook Technologies, "Quest 2," https://www.oculus.com/quest-2/, 2022.