Virtual Reality and Structures Education?

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Abstract

As Artificial Intelligence, Virtual Reality, and Augmented Reality become more ubiquitous, it is useful to explore their applications in education. Will there be benefits to including more digital tools in the classroom for this entirely digital generation? For example, can an interactive 3D representation of a building's structure aid student learning about the system and load flow? This paper will present the in-progress results from a collaborative research project entitled, "Virtual Reality as a Vehicle for Education in the Domains of Building Systems and Construction Materials." This funded educational research project was designed to test how immersive experiences such as virtual reality might influence the understanding of load paths in a building. The presentation will introduce the collaborative team of civil engineering and architecture, explain the goals of the funding organization, and describe the student groups being tested. The research methods will be outlined including the IRB process, the design of the virtual reality experiment, and creation of the evaluation mechanisms. Also, the outcomes from a student survey about the experience will be shown. With three years of testing completed, incomplete results will be shared as well as incomplete conclusions. Though using the same testing mechanism, the results vary significantly by discipline and remain inconclusive for architecture students. Lastly, there will be some discussion of research quandaries, lessons along

Introduction

This research project began in 2021 with the aim of testing the potential that Virtual Reality (VR) has within the classroom. In particular, could VR help students understand the three-dimensionality of building structure and more difficult concepts such as load transfer within a building? For both structural engineering and architecture, design professionals have the experience of seeing a building conceptualized on paper and then transforming into a physical building. This knowledge aids the professional, but this experience is not often available to students. Could a building modelled in virtual reality be a tool to help students conceive structure in a more wholistic manner? To test this research question, the team designed an immersive experience, wrote and administered assessments, and analyzed the data.

Research Project: Virtual Reality as a Vehicle for Education

The structure of this research project, "Virtual Reality as a Vehicle for Education," included obtaining funding, establishing research partners, determining study participants, and gaining approval from University's Institutional Research Board.

Funding

Located within the College of Engineering is a program dedicated to supporting innovation in engineering education. The College of Engineering provides funds through multiple competitive grants to aid with the implementation of education research projects. The funding encourages faculty to be as innovative in teaching as they are in conducting research. A requirement of the funds is to conduct educational research as part of the project. In other words, beyond designing the innovative educational approach, the team needs to test it with accepted pedagogical research methods. An additional emphasis of the program is a collaboration of faculty from various parts of the campus. While hosted by the College of Engineering, partners on awarded projects have included faculty from computer science, journalism, English, math, physics, the medical school, and of course, architecture.

Applications are taken each year and awarded by the dean of the College. Once a project has been successful in receiving funding, the team is assigned a coach who meets regularly with them. There are also other educational opportunities the team members can attend through the College of Engineering.

Stages of Development

To date, there have been three stages of this project with a fourth ongoing.

Stage 1 (2021-2022): Project Start up. Designing the VR environment in a campus building using existing Revit model. The budget ($8,300) allowed for VR Headset Purchases (10), Software, and a Graduate Research Assistant.

Stage 2 (2022-2023): Project refinement. The goal was to make the VR experience more complex so that students use higher level skills identified on Bloom's taxonomy. It was hoped that the tasks within the module would help students move from the early stages such as "Remember and Understand" to "Evaluate and Analyze." The budget ($12,325) allowed for further student wages to improve VR models.

Stage 3 (2023-2024): Continued refinement of the VR module. Emphasizing again "Evaluate and Analyze." The budget ($30,200) provided for more Graduate Research Assistants, and conference travel.

Stage 4 (2024-2025) (ongoing): The development of more modules within the VR environment to emphasize curiosity, connections, and creating value for the students. This is to be accomplished by giving students the ability to choose beam sizes and types while witnessing the results. Also, there is an emphasis in using pseudo-haptic feedback to allow students to "feel" stiffness. The Budget ($30,200) provided for Graduate Research Assistants and conference travel.

Research Team

The project team was led by an assistant professor in civil engineering who themselves had significant experience with gaming. The team also included a teaching assistant professor in civil engineering, with an emphasis on engineering education research, a teaching associate professor in computer science (specializing in visual computing), and an architectural structures professor. Joining the team this year is a research assistant professor researching integrative tools within sensing systems. Most importantly, however, are the graduate students with one completing a PhD in Civil Engineering and the other student obtaining a joint master's degree in architecture and civil engineering. Both these students built and enhanced the VR environment so that it could be used for this experiment. The student who was both in architecture and civil engineering came to this project after spending significant time designing their own video game.

Student Participants

The experiment was conducted in two courses – one in civil engineer and the other in architecture. The civil engineering course is a smaller course with approximately twenty students and taught in the senior year. The course, Design of Structural Systems, examines the entire structural design process from a civil engineering perspective including the design criteria, structural scheme, computer-aided proportioning, and cost. The architecture course, Structural Fundamentals, is much larger with an average of one-hundred students and taught in the sophomore year. It is a basic architectural structures course covering equilibrium, force distribution, member behavior, and mechanics of materials.

In the senior-level engineering course, the students were asked to complete a two-dimensional assessment and then partake in the virtual reality module. Each civil engineering student would receive 2% extra credit. For the architecture class, the students were tested by lab section with six to seven labs per class. Students were given a brief lecture on how tributary area is calculated and asked to take a quiz on the learning management system for the course. Students were asked to participate in the VR environment and again asked to take a quiz on the learning management system. With the large number of architecture students, the experiment was conducted over two class days within the same week. Architecture students were also given extra credit through quiz grades. For both courses, students were given the ability to decline participation in the experiment and alternate means of achieving the extra credit would be made available. Lastly, students were given in both courses a brief survey about their VR experience.

Institutional Review Board

Prior to the experiments being conducted, the research team needed to have the project reviewed by the university's institutional review board (IRB). Any research conducted with human subjects is to be reviewed to ensure the ethical projections of the human subjects. Ultimately, because this project was testing students as students (and not something more intrusive), the project received an "exempt" status. However, this did not mean that the project was free from IRB (or ethical) requirements. Exempt status means that the IRB reviewed the project and deemed it as minimal risk to the participants and that ongoing oversight by the IRB was not necessary. In order to enroll students in the experiment, students were recruited using IRB approved recruiting material (ensuring the language protected the interest of the students); the assessment tool was reviewed as was how the credit was given to make certain it was equitable, even with students who did not participate; and students were asked to sign IRB-approved consent forms. Additionally, the data had to be anonymized and protected, so a data management plan was submitted for approval. Any changes to the project that differed from the original description needed to be reviewed (and there were a few) and again approved. The process was not difficult, though it needed to be carefully considered, and time budgeted in the schedule.

The VR Experience

The VR simulation was designed to meet the needs of both the engineering and architecture class. The civil engineering professor tested to see if a better understanding of moment, shear, and deflection was gained, while the architecture class was testing for tributary area and load flow. The VR experience was constructed in Unity. To begin the project, a Revit model of the building was imported into Unity using a dedicated software program. The Revit model was of a new building on campus and the design firm assisted with the project by sharing its model. The Revit model was manipulated so that the exterior cladding could be turned on and off, and the building structure was the focus. The students wore Oculus Quest 2 VR Headsets with joysticks in each hand. Prior to the test, the research team would set up a separate classroom with the headsets, priming the simulation and marking out the test space on the floor. The headsets had to be reset after every group engaged with the simulation. Students tested in groups of 10-12 students depending on the number of working headsets at the time.

Fig. 1. Students participating in the experiment. (Credit: Author).

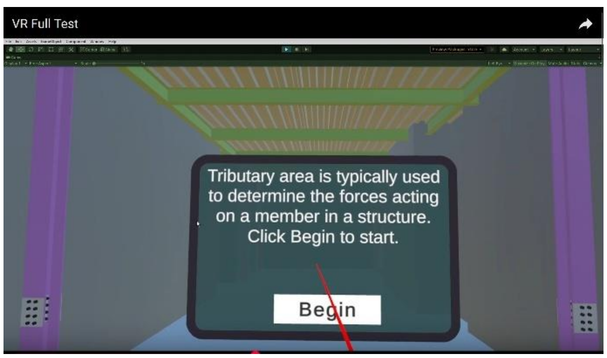

Fig. 2. Image of the VR simulation. (Credit: Jon Guttello).

Once in the VR environment, students could view the space and select different lesson "chapters" and "teleport" to visit. Based on the advice of the computer science team member, movement was limited, and students went from one space to the other by selecting the "teleport" command. Too much movement can cause unease for the participants within the VR environment and can be dangerous when moving in the actual classroom.

Students were given eight lessons to visit, and it was advised that the architecture students visit chapters one through five. However, they were allowed to visit as many chapters as they liked within the given time, around fifteen minutes. Most architecture students choose to remain for only ten minutes in the VR simulation.

The chapters consisted of:

- Chapter 1: Members. Visually defining beams, girders, columns, and braces.
- Chapter 2: Forces. Examples of tension, compression, shear, and moment in the members in the building.
- Chapter 3: Member Forces. Examines distributed load and load distribution acting on members in the building.
- Chapter 4: Loading. Visualizing dead and live loads.
- Chapter 5: Tributary Area. Demonstrating the concept of load collection among the members.
- Chapter 6: Beam Diagrams. Shear and moment diagrams on building members and their calculations.
- Chapter 7: Column Loading. Tributary area, loading diagrams, and calculations within the building.
- Chapter 8: Deflection limits. Deflection diagrams, calculations, and active loading onto a beam.

Each experience was constructed to visualize a concept from class and allowed some student interaction with those concepts. Seeing a member animate in compression, for example, was thought to be more instructive than flat 2D diagrams used to illustrate the mode of loading. For architecture students chapters one through seven reinforced concepts already discussed in class, with the exception of tributary area.

Because of the size of the class, and with the idea that perhaps the timing of the use of VR would be important, approximately half the students were asked to listen to a traditional lecture on tributary area first and take the online quiz. The other students were asked to participate in the VR simulation first, followed by taking the quiz. On the second day of testing (the next lab period), the students switched with the VR groups staying for lecture and those who had not yet interacted with the VR environment to do so, once again followed by a quiz.

Fig. 3. Image from tributary area unit. (Credit: Jon Guttello).

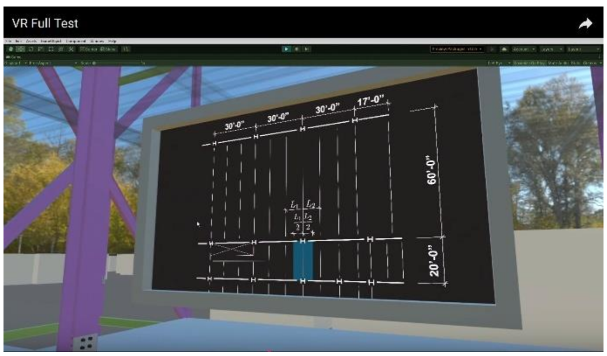

Fig. 4. Image from tributary unit. (Credit: Jon Guttello).

Students in the architecture course participated in the VR experiment in the spring of 2022, 2023, and 2024. In 2022, the running of the experiment proved challenging with several of the participants not fully participating either with the VR or the quizzes. This can be attributed to the inexperience of the onsite research team who was facilitating the experiment for the first time and that students were left an inadequate amount of time to participate. The results from the Spring of 2022 are thus not included here.

Evaluation Mechanisms

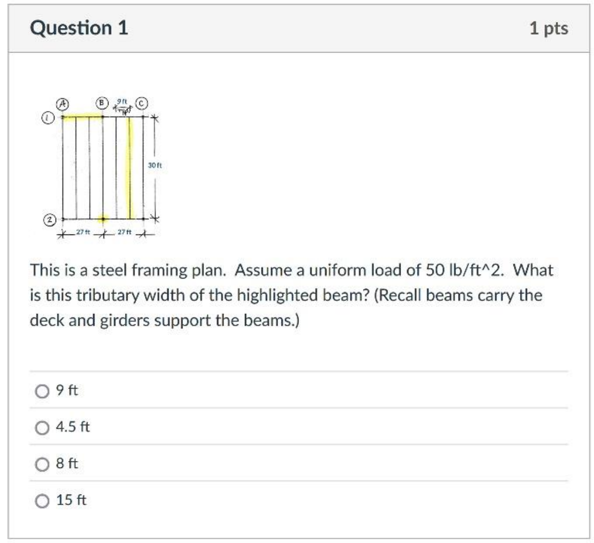

Fig. 5. Image from an online quiz.

After the students participated in the VR simulation, evaluation mechanisms were given to the students to try and see if the VR experience helped their understanding. The "quizzes" were given both before and after the exposure to the VR and the results would be compared. The evaluation mechanisms differed by course and methods. The architectural quiz was composed of five questions and asked the students to calculate the tributary area on a beam, girder, and column. They were then asked to identify the correct free-body diagram for the beam and for the girder. The quiz used both two- and three-dimensional images. The students alternated their experience of lecture or VR environment, and the students were given a quiz with the same question format with only the magnitudes changed. Students took the quiz as they returned to their labs.

The civil engineering course used a paper format and was completed by hand. Their quizzes used an alternate three-dimensional structure, and questions were asked around the topics of shear, moment, and deflection.

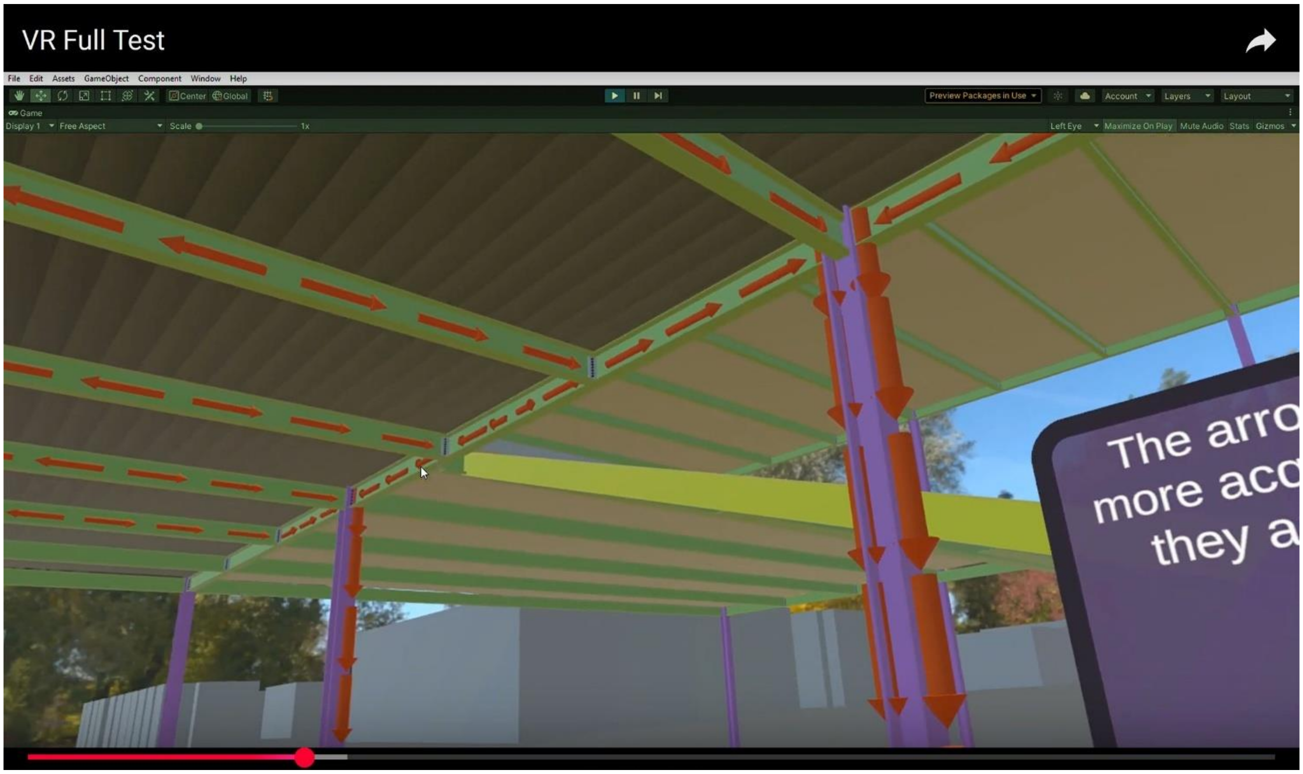

Fig. 6. Load flowing in the virtual reality simulation. (Credit: Jon Guttello).

Outcomes

Evaluating the Quiz Results

After the students took both the quizzes, the learning management system automatically graded the quizzes. Students who did not complete both quizzes or did not attend both sessions (the lecture and the VR simulation) were removed from the quiz pool. This meant that there were 75 students in spring 2023 and 91 in the spring of 2024. The results were exported into excel and quickly anonymized. The two quiz grades were compared against one another. The results of the testing can be found in the tables below (Table 1 & 2).

The results from 2023 seemed to show that the VR simulation slightly improved the understanding of the students on tributary areas. The more convincing value was that of the students who attended the lecture first and then participated in the VR simulation. Over half the students saw improvement in their quiz grades. Perhaps, then, this was an approach that could be taken – concepts are taught in lecture, and a VR simulation would strengthen the students understanding of that concept. The experiment was conducted again in Spring 2024 with the same approach in dividing the students. The hope is that the results would validate the conclusion that VR simulations enhanced learning when instruction occurred prior to exposure to it.

However, the results from 2024 seem to negate what was found in 2023. There was neither significant improvement from the first stage to the second, nor one method demonstrating a priority over the other. The overall improvement was down in both testing methods, and over half the quiz scored worsened from the first to the second.

VR First	#	Percent
Improved	16	37.21
Stayed the same	13	30.23
Worsened	14	32.56
Total	43	

Lecture First	#	Percent
Improved	18	56.25
Stayed the same	6	18.75
Worsened	8	25
Total	32	

Overall	#	Percent
Improved	34	45.33
Stayed the same	19	25.33
Worsened	22	29.33
Total	75	

Table 1. Quiz results from 2023.

VR First	#	Percent
Improved	16	31.37
Stayed the same	7	13.73
Worsened	28	54.90
Total	51	

Lecture First	#	Percent
Improved	12	30.00
Stayed the same	7	17.50
Worsened	21	52.50
Total	40	

Overall	#	Percent
Improved	28	30.77
Stayed the same	14	15.38
Worsened	49	53.85
Total	91	

Table 2. Quiz results from 2024.

What are your feelings towards using a virtual reality headset?

	2023	2024
Very Unhappy	5.0%	5.2%
Slightly Intimidated	3.8%	5.2%
Neutral	27.5%	24.0%
Slightly Curious	38.8%	42.7%
Extremely Excited	25.0%	22.9%
Participants	80	96

Have you ever used virtual reality in the past?

	2023	2024
No	30.0%	29.2%
Yes, for video games	60.0%	56.3%
Yes, for movies/videos	2.5%	6.3%
Yes, for learning	5.0%	5.2%
Yes, for other	2.5%	4.2%

How comfortable do you feel using virtual reality?

	2023	2024
Very Comfortable	13.8%	11.5%
Comfortable	30.0%	30.2%
Neutral	52.5%	47.9%
Uncomfortable	3.8%	8.3%
Very Uncomfortable	0.0%	3.1%

Table 3. Combined results from student experience survey.

Civil Engineering Experience

The civil engineering course is given in the senior year with fewer students: 12 in 2022, 21 in Spring 2023, and 25 in Fall 2023 (58 total). Similarly to the architecture course, students were split into two groups with one experiencing the VR simulation first and the other an exploration with 2D drawings followed by VR.

In the Civil Engineering course, students who experienced the VR environment first saw an 11% percent increase on their quiz scores, while those who started with the experience of 2D drawings had the average quiz grade remain the same. There was notable improvement for the CE students over the three years for students who utilized VR first.

Experience Surveys

In addition to the quizzes, paper surveys were handed to the architecture students as they entered the VR classroom, and collected as the students left the room. The intention of the survey was to better understand how comfortable the students were with the VR headset and simulation. If most of the students were uncomfortable with it, then perhaps further research would not be a valuable pursuit, for example. The results of the survey demonstrated that around a tenth of the classes were unhappy or intimidated, while over half had tried VR for various purposes; prior educational use of VR approached 5% (Table 3). Two additional questions were given in 2024 asking about the experience in the VR model and future use (Table 4). Only 7% of the students felt uncomfortable navigating the VR simulation model, and 65% were comfortable or very comfortable. Additionally, 66% of students wanted further learning experiences in VR with only 10% opposed. This demonstrates that VR could be an appropriate format for learning and students were open to further learning experiences with VR.

How comfortable do you feel when moving and navigating through the model?

	2024
Very Comfortable	14.6%
Comfortable	51.0%
Neutral	28.1%
Uncomfortable	6.3%
Very Uncomfortable	1.0%

Would you want VR to be incorporated into other learning experiences?

	2024
Yes	65.6%
No	10.4%
Maybe	25.0%

Table 4. Questions specific to the 2024 experiment.

Research Quandaries

The question remains: why were the results for the architecture students inconclusive? Here are some conjectures:

<u>A more developed sense of space:</u> The computer science team member, who specializes in visual computing, suggests that given the visual training of the architectural sophomores (three, almost four, semesters of design studio) it may be that their three-dimensional visualization skills are more developed than that average person and engineering students. The visualization that the VR experience provided may not be so different to how they are already thinking. This would need further investigation.

<u>Class size:</u> The course is a requirement for the entire sophomore class meaning that there are multiple lab

sections. Students moved between classrooms; the VR experience was limited in time; and the students did not have a quiet place to take the follow-up quiz.

Potential Adjustment: Perhaps the number of students be reduced with a selection of class, rather than the whole.

<u>Quiz questions are unprecise:</u> The questions assumed that the students knew the difference between a beam, girder, and column. Despite discussion of different uses, the determination of different structural behaviors, visually identifying these members in VR, and clear definitions provided in two classes prior to this point, students will refer to the columns as “vertical beams.”

Potential Adjustment: Perhaps the questions could be revised to highlight only the members being sought.

<u>Quiz format:</u> Students were asked to take the quiz on their own after either the lecture or the VR experience. They were given the entire lab period to take the quiz, and they needed to logon onto the class LMS to take it. Though the students were encouraged to take the quiz immediately after, some did not. The LMS was chosen as the tool because of the number of students for the ease of grading and anonymization.

Potential Adjustment: Would paper be better? This way the quiz could be given immediately after and in the same location as the lecture or VR experience. Another option might be for students to take a quiz on a tablet, but this would require the purchase of ten or more. Either proposal would require likely four labs sessions for testing as the time for the quiz would need to be incorporated.

<u>Misaligned Goals:</u> For the students, the experiment was a chance at extra credit. In the initial testing of the VR module in 2022 some students would put on the headset and remove it immediately after. This was meant to follow the directions, but the behavior indicated that they were not really interested in participating. Students, also, may take seriously the lecture on the topic as well as the VR experience, but be distracted when taking the quiz or not give their full effort when taking the quiz.

Several students did not complete both portions of the experiment – attend lecture and the VR simulation. For example, in Spring 2024, there were 127 students, but only 91 managed to participate in the full experiment. Of the remaining students (36), 25 students took the quizzes anyway and their quiz data had to be pulled from the study. Some of this may be due to the time of year the experiment occurred – at the end of the semester.

This category is not to blame the students, but rather to perhaps identify the mismatch between the intent of the team to learn about educational methods and the sophomore students’ desire for some extra points. Students were enthusiastic about participating, and it was likely the experiment design and facilitation that caused a problem.

Potential Adjustment: A smaller group of students could be selected to participate, but the selection would need to be equitable and alternate extra credit given.

Of course, the influence of the experiment on the students and the results could be a combination of any or all of these suppositions, or perhaps something else, too.

Lessons Learned

The lessons learned included observations about the VR simulation to the basics of facilitating such an experiment.

The VR experience was a success based on the student responses, and this had to do with careful consideration of the choreography of the modules within it and transportation between them. However, there was a maximum amount of time that the students wished to stay in the simulation (about 10 minutes).

The experiment itself took more time than anticipated. Students moved between rooms; the consent forms and surveys had to be distributed and collected; and the headsets had to be reset after every group. The lab sessions were 80 minutes each and within that time several groups of students had to complete the testing. All the movement, resetting, and assembly of students took a good proportion of the limited time to test the students.

The testing and experimentation take a team of committed individuals to construct and facilitate it. For the architecture class, up to 120 students had to be coordinated over two lab periods. This involved three to four project staff (graduate students) who were resetting the VR headsets, six or seven teaching assistants, and one to two professors directing the students between rooms. The VR design team involved four professors with graduate research assistants. The graduate research assistant who was completing a degree in both civil engineering and architecture was invaluable as they could see the needs of both disciplines and help to construct it in the VR model.

Overall, more control is needed for the experiment. Between moving locations and students having to initiate the quizzes themselves (and on their own time), there is too much time for students to get distracted. Also, when the quizzes are taken in a large studio environment, concentration may not be at its highest.

Conclusion

This study was established to examine the potential of incorporating virtual reality into the teaching of structures in both architecture and civil engineering. The study seemed to affirm that students were open to such an experience and an increase in the use of this technology. Building structure is a three-dimensional system, though often in both disciplines, the structural members are understood two-dimensionally by students. With its immersive and three-dimensional qualities, virtual reality has the potential to improve a student's understanding of the complete system.

The results of the study demonstrated different results per discipline. Civil Engineering, traditionally with less visual learning training, seemed to have a larger increase in understanding of the system as demonstrated by the evaluation mechanism for the experiment. For architecture, the results were inconclusive. However, as indicated here there may be faults within the testing and evaluation regime.

Architecture students were interested in the experiment and excited to participate. Even though not conclusive at this stage, the experiment seems to be something worthwhile, especially as faculty are faced with several new technologies that the students may be already incorporating into their daily lives - Artificial Intelligence, Virtual Reality, and Augmented Reality. The experiential survey indicated that close to 70% of the architectural students had experienced virtual reality. As long as the research team is eager and further funding can be gained, continued refinement and testing will occur, including in Spring 2025.

Acknowledgements

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