Integration of Virtual Technology in Civil Engineering Education

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Integration of Virtual Technology (VT) in Civil Engineering Education: Enhancing Learning Outcomes

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While a survey revealed limited use of Artificial Intelligence (AI) and Virtual Technology (VT) tools among Penn State Harrisburg civil engineering students, strong interest in their application exists. This paper explores integrating VT software like Revit models and VR programs (Sentio VR, Resolve, Arkio) to improve learning outcomes. By combining advanced tools such as Revit models, Sentio VR, Resolve, Arkio, and more, students can gain a deeper understanding of complex engineering concepts, apply theoretical knowledge in practical scenarios, and improve their problem-solving skills.

The use of personalized learning experiences and feedback provided by Artificial Intelligence (AI) technology further enhances student engagement and maximizes their potential in civil engineering. The paper focuses on VR's use in upper-level courses, allowing students to interact with 3D models in simulated real-world scenarios, providing crucial hands-on experience for classroom use and projects. This cutting-edge approach in education not only prepares them for success in the field of civil engineering but also allows them the skills to thrive in a rapidly evolving technological landscape.

Overall, this paper will cover the benefits of using VT in civil engineering courses and show some examples of how students have used these. The combination of all these VR programs with Revit in civil engineering offers each student a dynamic and innovative learning environment that fosters creativity, critical thinking, and problem-solving skills. This approach not only enhances student engagement but also prepares them for the challenges and opportunities present in the modern engineering industry.

Keywords: Virtual Technology, Civil Engineering Education, Learning Outcomes, Revit, VR Software, Artificial Intelligence, Personalized Learning

Introduction

Virtual Technology is currently changing the construction industry. There are many programs out there that can help designers turn their 3D design into a VR-compatible model that can be seen lifelike as a walkthrough. In addition, the industry has been using VR in many ways such as:

1. Communication: speaking with a client or worker off-site
2. Walkthrough: viewing a building designed from the standpoint view and walking through it before it is built. This can enable one to experience what the building will look and feel like and understand the layout.

3. Safety and training: VR is being used in the construction industry to train more effectively by utilizing video learning, microlearning apps, and lab apps. These also allow training for employees, practical guidance, how to use machinery, and to practice safety overall on-site.
4. Labor costs: VR can reduce labor costs when it is combined with intelligent machinery. One can preview, calculate, and inspect remotely instead of placing equipment and operators on site.
5. Timeline: 3D models created through programs such as Revit, can allow one to see project conditions change instantly over time before it is being built.
6. Rework: VR allows for a more up-to-date view of the project conditions and helps to prevent more work due to miscalculations or mistakes.
   Civil engineering education plays a crucial role in shaping the future of infrastructure development and sustainable living. As technology continues to advance rapidly, traditional teaching methods face challenges in keeping pace with the evolving demands of industry. This is where VT emerges as a powerful tool for enhancing learning experiences and fostering the development of essential skills in civil engineering students. (Fallon-O'Leary, 2023)

Through all these benefits stated above, it is crucial to open these learning opportunities to students so they can adapt to the new and changing construction industry. This paper is continued research from a survey that was conducted last year. A survey on the use of AI in engineering education was distributed to a total of 107 junior and senior-level civil engineering students. The survey consisted of questions related to their knowledge, frequency, benefits and challenges, and suggestions for future use of AI tools in engineering education. The outcome was surprising because the survey showed that 60% of the students did not use it and claimed that it was not accurate enough in the responses. The students that used it mentioned that they only use it as an assistant and to understand the lecture topics better. (Vidalis and Subramanian, 2023)

The purpose of the survey was to gather valuable insights regarding the integration of AI in engineering education from the perspective of students. By understanding their attitudes, preferences, and challenges. The students' feedback from the survey has helped them make decisions on what new technologies to use in the classroom. Therefore, from the feedback we received in the past, we now aim to explore the integration of VT software in civil engineering curricula. This is also continued research that will analyze the impact on student learning outcomes based on the VR tools used in the classroom. Many learning approaches maximize student learning. The use of Technology-Enables Active Learning (TEAL) is one example where the learning approach is student-centered. This is also another research where student learning can be maximized by the following three methods:

1. Hands-on experiments and interactivity
2. Visualization and engagement from technology-enabled
3. Inquiry-based science instruction (Mackin, 2012)

This paper explores applications and delivery methods of VR in engineering using specific programs recently used or will be used in students' capstone projects as well as in class.

Benefits of VT in Civil Engineering Education

VT offers a plethora of advantages for civil engineering education, encompassing various aspects of the learning process. These benefits can be categorized into three key areas: deepening conceptual understanding, bridging the gap between theory and practice, and personalized learning and feedback. All these areas have been tied with learning applications that will get students ready for the real world.

Deepening Conceptual Understanding

VT tools, particularly those employing virtual reality, enable students to visualize and interact with complex engineering concepts in an immersive 3D environment. This allows them to gain a deeper understanding of spatial relationships, structural dynamics, and design elements within an interactive and engaging context. For instance, students can virtually explore bridges, buildings, and construction sites, observing load distribution, material behavior, and construction processes in real-time. This interactive experience provides a significant advantage over traditional static visualizations, fostering a more comprehensive and intuitive grasp of complex engineering principles. One-way students have used this application in their capstone project course is by creating walkthroughs from the model they have created. The program that was used to create their models was Revit, an Autodesk software program. The reality of creating a walkthrough, using the VR goggles, was to use Sentio VR and bring the model into a VR realm.

Bridging the Gap between Theory and Practice

The traditional approach to civil engineering education often separates theoretical concepts from practical applications. VT bridges this gap by providing students with opportunities to apply their theoretical knowledge in simulated real-world scenarios. VR software allows them to create and manipulate 3D models, virtually interact with construction equipment, and analyze the performance of various design solutions under different conditions. This practical engagement fosters the development of critical thinking and problem-solving skills applicable to real-world engineering situations. One example that was used in the Construction Management II (CM II) course, for the topic of safety on a construction site, was to have students experience a life-like walkthrough of a working project. In this lab application, they got to experience safety hazards and concerns seen on site.

Personalized Learning and Feedback

AI-powered technologies can further enhance the learning experience by enabling personalized learning and feedback mechanisms. VT platforms, such as lab applications, can integrate AI algorithms that analyze student performance and tailor learning modules based on individual strengths and weaknesses. Additionally, AI can provide real-time feedback on student designs, identifying potential issues and suggesting improvements, thus enhancing their learning efficiency and critical thinking skills. Students have experienced this through certain lab applications that would allow them to inspect a project site. Case studies of certain examples and applications used in class are explained further in this paper.

VR Software Used

Several VT software programs have proven beneficial in civil engineering education, each offering unique functionalities to enhance learning. Some of these programs that students have used or are under consideration are as follows:

- **Revit:** This building information modeling (BIM) software provides students with the ability to design and create detailed 3D models of buildings and infrastructure projects. Revit facilitates a holistic understanding of design, construction, and operational aspects, allowing students to visualize and assess their projects from various perspectives.
- **Sentio VR:** This VR platform allows students to explore and interact with 3D models of construction sites and infrastructure projects in an immersive environment. Students can virtually walk through, analyze, and manipulate various elements of the model, gaining valuable insights into spatial relationships, construction sequencing, and potential safety hazards. (Sentio VR, 2024)
- **Industrial Training International (ITI) Construction Hazard**: This lab application allows students to identify hazards and train them using VR. This tests a candidate's ability to identify hazards on site, tests knowledge of construction site hazards, and teaches best practices for on-the-job sites to create a safer work environment. (ITI, 2024)
- **Resolve**: This VR platform is similar to Sentio VR. It also allows students to explore and interact with 3D models that they have created. Students can virtually walk through, analyze, and automatically keep their models up to date by using the cloud. It also inspects BIM properties, measures, and sketches. They also can gain valuable insights into spatial relationships, construction sequencing, and potential safety hazards. (Resolve, 2024)
- **Arkio**: This VR platform is more to experience the environment of the 3D model. Students can design interiors, sketch/change buildings in their 3D model, and design the environment and surroundings of the building. This allows different design options on-site for the student to create. (Arkio, 2024)

Some of these programs have been adopted, used for certain lecture topics, used for senior capstone projects, or are under review for future adoption.

Examples of VT Usage in Civil Engineering Education

The VR programs discussed in the previous section are some that have been used in a classroom setting for educational purposes. Penn State Harrisburg courses integrating VR technology include Construction Management II, Project Information Modeling (PIM), Construction Estimating, and the Senior Capstone Project. Table 1 details the specific classes, the utilized VR software, its application within the course, and the corresponding learning outcomes achieved.

Table 1: VT Programs Used for CE Courses

Course #	Course Title	VT Software/Applications	Use	Skills Developed	Learning Outcomes
CE 424	PIM	Revit and Sentio VR	Creating 3D models for walkthroughs	Proficiency in 3D modeling, problem-solving abilities, collaboration, skills, and ability to communicate complex ideas through immersive experiences	Improved spatial awareness, enhanced visualization, increased technical proficiency with Refit, deeper understanding of design principles and modeling
CE 458	CM II	Revit and ITI	OSHA inspections and cost estimating	Communication skills, teamwork, problem-solving	Proficiency in accuracy, ability to create estimates based on 3D models, Improved understanding of safety protocols, enhanced ability to identify hazards in a simulated project site, increased proficiency in inspections, development of critical thinking skills when making decisions
CE 435	Construction Estimating	Revit		Communication skills, teamwork, problem-solving, critical thinking skills when analyzing cost data, understanding of how design decisions impact project costs	Proficiency in accuracy, ability to create estimates based on 3D models
CE 438W	CM Capstone Project	Revit, Sentio VR, and Resolve	Creating 3D models for walkthrough, inspection, cost estimating, presentation	Enhanced ability to detect issues or defects, improved spatial awareness and attention to detail, and all the above-mentioned	All the above-mentioned

<u>CE 438W Case Study</u>

The Civil Engineering Senior Capstone course integrates real-world projects into a three-part curriculum focused on Construction Management, Structural Engineering, and Transportation Engineering. Students form interdisciplinary teams to tackle a comprehensive project. This semester, the challenge is to design an addition or alternative project for the new West Wing of Penn State University's main campus Engineering Building. Student proposals have ranged from green roofs and additional floors to an enclosed pedestrian walkway connecting engineering buildings.

Every spring, the School of Science, Engineering, and Technology hosts a Senior Capstone Conference where students showcase their projects to faculty, industry professionals, and the public. Judges select the best project in each engineering discipline (computer, electrical, mechanical, and civil) and award an overall winner. The Senior Capstone Projects are judged on each group's PowerPoint presentations and poster board. This year, however, Virtual Technology is being introduced to enhance the experience. Students are currently using Revit software to create 3D models of their projects. These models will be transferred to Sentio VR, allowing judges to virtually walk through and interact with the designs in an immersive environment. Figure 1 depicts the West 1 Engineering Building modeled in Revit, ready for VR integration. Each group will have a different model that will be shown and experienced by judges to be able to walk through all designs using the VR goggles.

Figure 2 showcases a section of the building with a cutaway view to reveal the interior of the engineering building. Joysticks are used with VR goggles to navigate in and around the building. This innovative approach empowers students to not only showcase their designs but also enables judges to virtually inspect them, make collaborative markups, and filter layers or materials for a closer look.

CE 458 Case Study

The Construction Management II course has taken a groundbreaking step towards enhancing construction safety education by incorporating virtual reality (VR) goggles. This innovative approach utilizes a program called ITI Construction Hazard, which throws students into a realistic job site environment brimming with workers, equipment, and potential hazards.

Some key features of this virtual lab are:

- **Immersive Learning:** The VR lab functions as a powerful virtual training and assessment tool. It replicates real-world scenarios, allowing students to experience and identify various construction hazards firsthand.
- **Active Participation:** Students actively navigate through the construction site, actively identifying and marking potential hazards. This fosters deeper engagement and knowledge retention compared to traditional methods.
- **Personalized Feedback and Improvement:** The program reviews identified hazards, assigns scores, and allows students to revisit sections to find any missed dangers. This personalized feedback loop empowers students to continuously improve their hazard identification skills.

Overall, this immersive VR experience offers a significant advantage over conventional methods. By allowing students to virtually inspect and analyze project scenarios, the program fosters a deeper understanding of construction safety practices, potentially leading to safer worksites in the future. Figures 3 & 4 showcase examples of hazards encountered: an open manhole that does not have safety railings or warning signs and a worker who is standing on an unstable ladder.

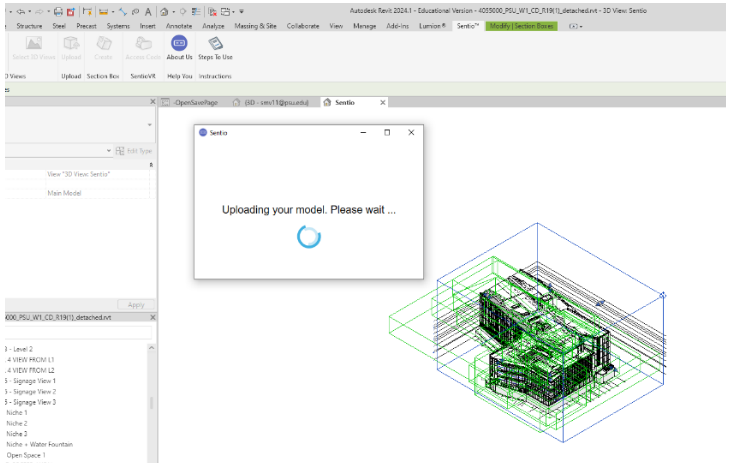

Figure 1: West 1 Engineering Building Model in Revit

Figure 2: Exterior West 1 Engineering Building Model in Sentio VR

Figure 3: Open Manhole Hazard (ITI Construction Hazard)

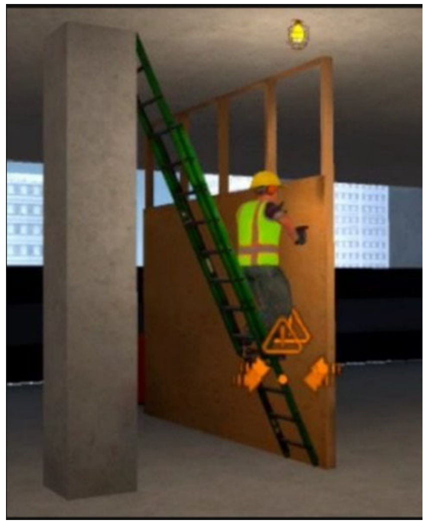

Figure 4: Man on Unstable Ladder (ITI Construction Hazard)

Student Feedback on VR Use

A short five-question questionnaire was given after the use of VR technology in the CMII course to find out the student's feedback and experiences. The questions that were asked were:

1. Have you used virtual reality technology in any other courses? If so, which one/s and to what extent?
2. How would you rate the ease of use of virtual reality technology compared to traditional approaches in class?
3. Do you feel more engaged when using virtual reality technology in class or for class assignments? Why?
4. In your opinion, has the use of virtual reality technology had a positive impact on your learning? Why?
5. Overall, how satisfied are you with using virtual reality technology in your course/s?

The survey was given to 14 students in their senior year. It was found that 64% did not use any VR technology before this course. The same percentage thought the use of VR technology was somewhat easy. All students mentioned that they felt more engaged when using the VR goggles because of the experience, being more connected to reality, stimulating what one sees, having a more hands-on feel, and better retention through engagement. Moreover, most of the students feel it had a positive impact on their learning because one can understand the subject more clearly visually than through traditional lectures. Lastly, students felt satisfied using the technology and would like to see it used on other courses.

Conclusions and Future Research

This paper highlights the significant potential of Virtual Technology for enhancing learning outcomes in civil engineering education. By integrating VT tools like Revit models and VR programs (Sentio VR, Resolve, Arkio), students can gain a deeper understanding of complex concepts, bridge the theory-practice gap, and benefit from personalized learning experiences.

The three major key findings using VR technology in engineering education is:

- VT fosters deeper conceptual understanding through immersive 3D visualization, allowing students to interact with engineering principles in a more engaging way (e.g., exploring bridges and buildings virtually).
- VR bridges the gap between theory and practice by providing simulated real-world scenarios. Students can apply theoretical knowledge in construction tasks (e.g., identifying hazards) and analyze design solutions (e.g., walkthroughs of 3D models).
- AI-powered VT platforms can personalize learning by tailoring modules based on individual strengths and weaknesses. Additionally, real-time feedback on designs can enhance critical thinking skills.

Some future research and implementation on using VR technology in engineering education is:

- **Longitudinal studies:** Investigate the long-term impact of VT integration on student learning outcomes, career readiness, and problem-solving skills in the workplace.
- **Faculty training:** Develop training programs to equip faculty with the necessary skills and knowledge to effectively integrate VT tools into their courses.
- **Assessment methods:** Create standardized assessment methods to evaluate the effectiveness of VT-based learning experiences in civil engineering education.
- **Collaboration platforms:** Explore the potential of collaborative VR platforms where students can work together on projects in a virtual environment.
- **AI integration:** Further explore the role of AI in personalized learning experiences and real-time feedback mechanisms within VT platforms.

Future research is also needed to see how students and the industry respond to the product of their projects. A questionnaire will be sent out to students and the industry regarding their performance, how they utilized the VT in their project, and lessons learned after their capstone project.

By continuing research in these areas, educators can leverage the power of VT to create even more effective and engaging learning environments for future generations of civil engineers. Overall, real-world projects in the engineering capstone course, as well as other courses, that use VT can help students bridge the gap between academic learning and professional practice while keeping up with technology.

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