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Augmented and Virtual Reality Resource Infrastructure for Civil Engineering Courses

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Augmented and Virtual Reality Resource Infrastructure for Civil Engineering Courses (Work-in-Progress)

1 INTRODUCTION

Extended Reality (XR) refers to all combined real-and-virtual environments and human-machine interactions generated by computer technology and wearables. XR refers to representative forms such as Virtual Reality (VR), Augmented Reality (AR), and Mixed Reality (MR). This group of digital experiences has received much interest in the educational world. The application of VR technology in education has been explored widely in literature [1], and recent advancements in VR technology are prevailing. VR has been implemented in various applications, including the education of medical students, first responders, and K-12 students [2]. One of the key characteristics of VR is immersion through audiovisual stimulus in the first person, making it a powerful learning tool [1], [3].

New technologies bring new challenges, advantages, and disadvantages in their implementation when being offered as an effective learning experience. An extensive literature review exposes these factors and provides new approaches to offering students the best educational experience. However, the implementation of VR in undergraduate-level courses has not seen widespread adoption for Civil Engineering education. At UConn's Civil and Environmental Engineering (CEE) Department, a VR laboratory was established with funding from the National Science Foundation (NSF) to expand the usage of AR/VR in the university setting. Potential challenges for widespread adoption include faculty education, lack of educational infrastructure for XR, and limited curriculum space to fit in this additional component. Therefore, a solid XR training infrastructure is desired to facilitate the adoption process.

This paper is a work-in-progress and will emphasize the development of the VR infrastructure for Civil Engineering courses. Three main tasks are involved in this project. The first task is to compile a broad literature review of the use of XR technology in Civil Engineering education to provide insight to the instructors. The second task is to develop a series of tutorials for hardware usage and software usage. The third task is to implement this training tool in courses and examine its efficacy for student performance and engagement. This paper uses this step-by-step procedure to create an XR training infrastructure so that VR can be used as a learning tool in the higher education of civil engineering and so that other institutions could benefit from this work. The outcomes of the first and second tasks are detailed in the following sections. To implement and examine the effects of the training tool, students enrolled in Senior Design will utilize XR technology to visualize their final designs on Senior Design Day, the conclusion of the course. Initial assessment regarding the implementation of VR technology will be obtained during the 2022 Spring semester through pre/post-assignment surveys and summative evaluations through Students' Evaluation of Teaching, which is conducted by the Office of Institutional Research independently and anonymously. Additional in-depth developments of survey questionnaires and statistical analysis will follow in the next academic year.

2 LITERATURE SURVEY

The use of digital devices in education follows in parallel to the advances of these technological pieces. From calculators to no-network personal computers to personal computers, mobile devices, and videogame consoles connected to the internet, educators seek new ways to take advantage of technological components to improve the learning process at all educational levels.

In this fashion, VR, with its particular head-mounted devices (HMDs), has been a new revolution in immersive experiences. It appears to be the next generation of the internet, taking into account the recent re-branding of Facebook Inc. to Meta Platforms Inc. [4]. Meta is putting more effort into developing the so-called "Metaverse," leading our general public, educators, and students to the new immersive virtuality, including its high-end Oculus Quest 2 wireless HMD device. Furthermore, the cost of VR technology is decreasing, offering more capabilities and comfort to the user in an industry expected to grow with a Compound Annual Growth Rate (CAGR) of 33.85% over the forecast period between 2021 and 2026 [5].

A virtual world is defined by three main features [6]:

- Interactivity: it exists on one computer but can be accessed remotely and simultaneously by a large number of people, with the command inputs of one person affecting the command results of other people.
- Physicality: people access the program through an interface that simulates a first-person physical environment on their computer screen; the environment is generally ruled by Earth's natural laws and is characterized by scarcity of resources.
- Persistence: the program continues to run whether anyone is using it or not; it remembers the location of people and things and the ownership of objects.

Castronova made this definition in the video game context, but it is applicable and adaptable to the educational context.

Extensive research has been conducted to explore the benefits of VR on all levels of the educative system, including higher education. The following examples show a comprehensive literature review with different approaches to a VR application in teaching and education.

Merchant et al. [2] focused on desktop-based VR instruction for teaching K-12 and higher education curriculum. The authors point to financial feasibility as one of the many reasons VR Technology was beyond the reach of schools. The cost of sophisticated devices, including procurement and maintenance costs, and the effort to train teachers to use these devices effectively are essential details to consider in the early implementation of VR technology. There are three desktop-based VR technologies: game-based, virtual worlds, and simulations. The gamed-based form is the most effective; however, games should be carefully designed to succeed as educational tools. Simulations are less effective because the time spent into the experience is less than games and virtual worlds.

Chavez and Bayona [7] identified 24 characteristics or attributes that must be included for the successful implementation of VR technology. These characteristics include interactive ability, immersion interfaces, animation routines, movement, simulated virtual environment, and evaluation strategy. Some characteristics are more important in one area than others. For example, in Medicine, the movement feature is vital for learning about the reaction of a person's body, whereas, in the Education field, the immersion interfaces are often used to learn through live experiences that are closer to reality. Additionally, the authors identified 17 positive effects of VR, including improving learning outcomes, living experiences that are closer to reality, intrinsic motivation, increasing level of interest in learning, and improved skills. In Medicine, skills were acquired or improved, while no meaningful learning effects were observed in Psychology education.

Feng et al. [8] conducted a systematic literature review of Immersive VR Serious Games (IVR SGs) for evacuation training and research. Building evacuation and indoor emergencies, such as fire and earthquake, towards serious games were investigated as alternatives to traditional approaches like videos, posters, seminars, courses, and evacuation drills. The authors focused on examining immersion through a virtual environment, where the participants could feel that they were physically inside the artificial environment. The authors noted the participants' experience and the hardware and software systems used to combine SGs and IVR-based training. Several pedagogical and behavioral outcomes were identified, including knowledge of evacuation best practices, self-protection skills, and spatial knowledge. Feng et al. [8] also mentioned the characteristics of the game environments identified during the study. This enviroments are navigation, static and dynamic hazard simulation, narratives – such as action, performance or instruction-driven, interactivity/non-interactivity with non-playable characters – as well as audiovisual and motion sense stimulation.

Jensen and Konradsen [9] reviewed literature related to HMDs in education and training for skill acquisition. The authors examined situations where HMDs are useful for acquiring cognitive skills related to remembering and understanding spatial and visual information, psychomotor skills related to head movements such as visual scanning or observation, and affective skills related to controlling one's emotional response to stressful or difficult situations. They also studied cyber-sickness symptoms due to HMD usage. Furthermore, they explored factors influencing immersion and presence when applying VR in education. Some obstacles to using HMDs in education and training were identified. Mainly, current HMDs are more entertainment-oriented and lack education-oriented content and design. The narrow scope and a limited number of studies require further and more rigorous research.

Suh and Prophet [10] discussed the state of immersive VR research in a systematic literature review of four relevant knowledge fields that use immersive technologies: education, entertainment, healthcare, and marketing. In particular, Suh and Prophet studied current research trends, major theoretical foundations, and research methods used in previous immersive technology research. Two main research trends were identified. The first trend studies the effects of unique system features of immersive technology on user experience. The second trend studies how immersive technologies enhance user performance through, for example, learning and teaching effectiveness, task performance, and pain management. The authors identified the flow theory as the most popular theoretical foundation employed in existing immersive technology studies. Other theoretical perspectives used were situated cognition theory, media richness theory, the Stimulus–Organism–Response (S-O-R) model, and the technology acceptance model. The experimental method and the survey method were the most implemented research methods. Suh and Prophet [10] provided a four-component (stimuli, organism, response, and individual differences) classification framework for immersive technology use. The authors conclude that more empirical studies are needed to theorize the effects of immersive technology use on user experience and performance.

Regarding Civil Engineering education, Wang et al. [3] specifically surveyed the application of VR technologies for education and training in the construction engineering field. VR technology used in the construction engineering context evolves from desktop-based VR, immersive VR, and 3D game-based VR to building information modeling (BIM) VR and augmented reality (AR). The authors indicate that desktop-based VR improved students' motivation and comprehension due to its stability and recent developments focusing on 3D computer models and virtual laboratories. Under immersive VR, HMDs combined with sensor gloves or controls withdraw the user from the physical world to virtual scenarios such as CAVE and VSAP. It was concluded that immersive VR was essential for improving concentration and giving trainees a measure of control over the environment. BIM VR has been applied in construction engineering to visualize the necessary data required in a practical building project through its life cycle, including design, planning, construction, operation, and maintenance stages. It was found that VR applications are primarily used in architectural visualization and design education, construction safety training, equipment and operational task training, and structural analysis education. Future directions for VR-related education in construction engineering include integrating with emerging education paradigms, improving VR-related educational kits, VR-enhanced online education, hybrid visualization approaches for ubiquitous learning activities, and rapid as-built scene generation for virtual training.

According to Radianti et al. [1], the interest in immersive VR technologies for educational purposes is relatively high, indicated by the variety of the research domains that have applied this technology in teaching. VR is depicted as a promising learning tool for higher education; however, the maturity of VR use in higher education is still questionable. These technologies have remained experimental and are primarily tested for their performance and usability. Radianti et al. [1] also reveal that very few design-oriented studies constructed their VR applications based on a specific learning theory, which serves as technical development guidance. Moreover, little research thoroughly describes how VR-based teaching can be adopted in the teaching curriculum.

Hain and Motaref [11] incorporated interactive AR models in a Mechanics of Materials course to improve students' spatial understanding and creativity and assist in permanently retaining the learned material. Students were separated into two groups and surveyed to measure the effectiveness of these models as a learning tool. The first group only had access to a traditional two-dimensional (2D) schematic, while the second group had access to a 3D model. More than 70% of students found that AR 3D models are beneficial to their learning, but they expressed that they preferred to see 3D models on the projector rather than navigating on their cellphone. They suggested that integrating the discussion of the 3D models with the lecture would help their learning. Only 31% of students participated in generating 3D models on their own time. Low reception of this activity can be attributed to its optional nature and the fact that students were responsible for learning 3D drafting on their own from instructional videos.

From the extensive literature, XR technology showed vast potential to improve students' motivation, comprehension, and engagement in education. Furthermore, the technology itself is mature enough to be implemented, and the cost of the technology is getting lower. Therefore, the next step is to establish an XR infrastructure to facilitate the adoption procedure for our courses.

3 AR/VR LABORATORY

The AR/VR laboratory was established in a 300 square foot classroom in building of UConn's main campus. Figure 1 shows the setup of this laboratory and its equipment. The following hardware is available for faculty and students:

- One (1) Alienware desktop (tagged as A in Figure 1) (www.dell.com/)
- Two (2) Alienware laptops
- One (1) Wireless HTC Vive system (www.vive.com/) (Figure 1 shows the antenna (C) and the base station (D))
- One (1) wired HTC Vive system
- One (1) 60 inch TV connected to the desktop (B in Figure 1)

The software installed in the computers is:

- SteamVR (store.steampowered.com/steamvr)
- Unity (unity.com/)
- eDrawings (www.edrawingsviewer.com/)
- SketchUp AR/VR viewer (www.sketchup.com/)

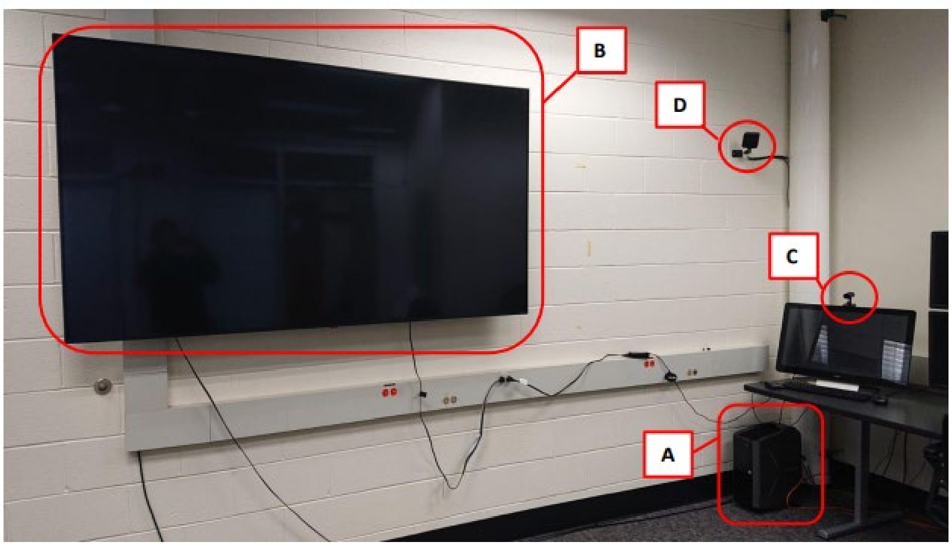

Figure 1. AR/VR laboratory: Standalone desktop equipment

More AR/VR lab equipment is shown in Figure 2, including an HTC headset (F), two controllers (G), a rechargeable battery pack (H), chargers (I), and a remote for the TV (J). It is planned to include Oculus Quest 2 (www.oculus.com/quest-2/) headset systems and more engineering software with native VR visualization like Revit and Civil 3D (www.autodesk.com/). A CEE

AR/VR lab guide was developed to show the students the hardware pieces of the Lab's VR system.

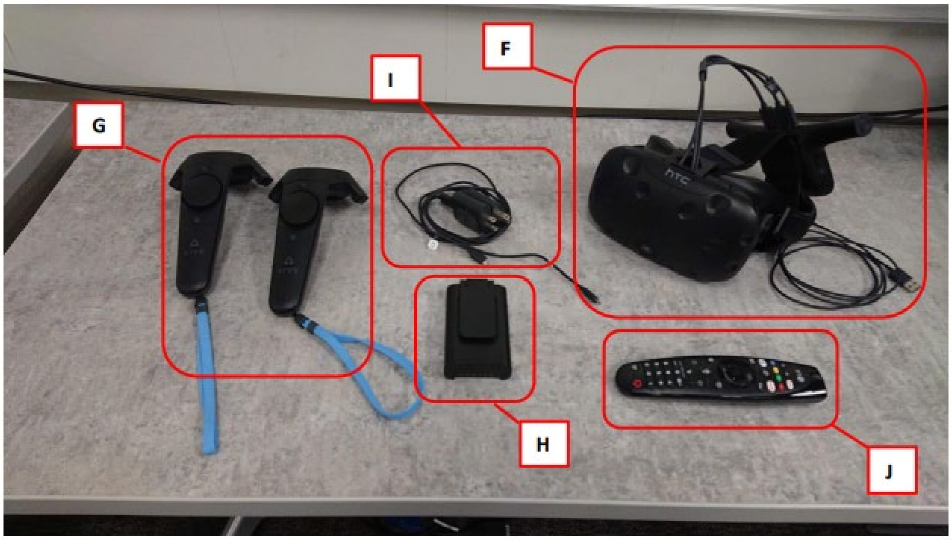

Figure 2. AR/VR laboratory equipment

4 AR/VR TRAINING MODULE IN BLACKBOARD

A new training online module using the Blackboard platform was created. This module aims to increase student engagement in the classroom through VR tools and to teach the 3D visualization of civil engineering projects.

The objectives of the online module are:

- Create a universal training module using the Blackboard platform for AR/VR technology
- Create courseware to demonstrate a challenging topic in a Statics course and compare students' engagement and learning outcome
- Teach senior students the use and application of AR/VR technology and assess their 3D visualization skills

Figure 3 shows the Welcome Page and learning components of the online training. The following sections explain each site module and discuss the training module development, benefits, and challenges. In addition, hyperlinks to relevant websites are included for other institutions to use in their learning module. Because this paper includes the references and raw links, the developed training site is transferrable to any educational platform, e.g., Blackboard or Canvas.

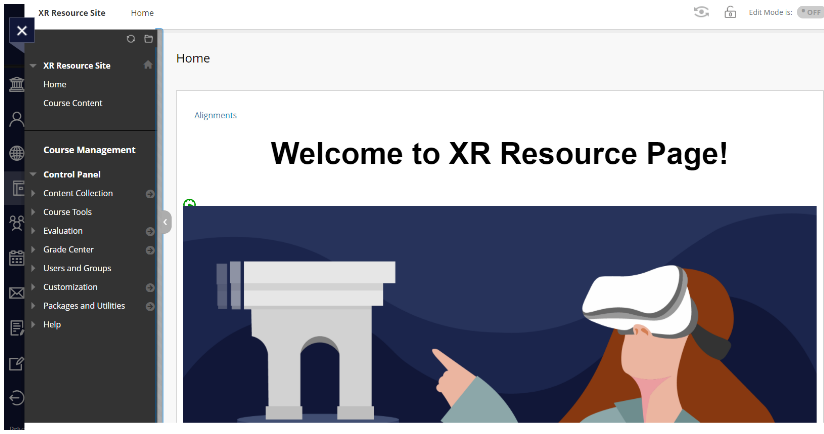

Figure 3. Training module welcome page

Component 1: Introduction material

The first component the student will access is introduction material that contains articles and videos that explain the XR (url1, video1), VR (video2), AR (url2, video3), and MR (url3) definitions. Additionally, the students can read articles about VR-related developments and advancements in other departments at the University of Connecticut, mainly video game design (url4, url5, url6, url7, url8).

Component 2: VR lab tutorial

The second component is a physical and technical description of the AR/VR laboratory. As mentioned earlier, Figures 1 and 2 depict images from the CEE AR/VR lab guide, which was developed to show students the hardware in the Lab's VR system. Regarding the technical description of the VR system, the laboratory has HTC VIVE hardware, which was launched in June of 2016, but at present is discontinued, so-called "the first generation VIVE development kit." This component also contains manuals (url9, url10), official HTC videos (url11), and links to developer forums (url12, url13, url14) where troubleshooting is discussed. Additionally, the low-cost Google Cardboard (https://arvr.google.com/cardboard) visor is included in this module, providing students with accessible options for their project development.

Component 3: Unity tutorials

The next component contains information regarding a game engine platform developed by Unity Platforms (https://unity.com). Despite Unity being a game-oriented software, it offers some advantages for students, for example:

- it is free for personal and student use;
- it has its own educational site (https://unity.com/learn), of course, game-oriented;
- there is a large amount of free online resources regarding its use, for example, YouTube videos and forums;
- it is compatible with other 3D file formats, making importing files developed in other software relatively easy.

Due to a large number of available online resources on the internet, more of them game develomet orienred, with a selection of Unity basic tutorial regarding objects and coding were included (video4, video5, video6, video7, video8). Furthermore, it contains relevant content selected for civil engineering applications, for example, how to set the Unity model for the VR visualization with HTC VIVE hardware (video9), importation from civil engineering industry software to Unity (url15), and landscaping (url16) for project presentation to clients.

Component 4: Solidworks/eDrawing guide

Taking advantage of the availability of Solidworks software (https://www.solidworks.com) for our institution's engineering students, a brief guide explaining how to visualize Solidworks models in VR is included on the site. An advantage to using this software is that the developer of Solidworks, Dassault Systemes (https://www.3ds.com), offers eDrawings visualization software for free (https://www.edrawingsviewer.com), which is VR compatible. Therefore, students can use Solidworks as a development path for their projects.

Component 5: XR examples

The next component of the training site is a page containing VR examples from different sources. Websites include Google's AR and VR sites, YouTube's VR Channel (https://www.youtube.com/360), Google Earth VR (https://arvr.google.com/earth), Solidworks (https://my.solidworks.com/cadmodels), and Sketchfab (https://sketchfab.com). Some of these sites offer VR content visualization online; hence, students can get ideas for their projects from these examples.

Component 6: Links to Libraries

Students can find some links to libraries that offer models (url17, url18) and textures (url19) for free. These features can be used for project landscaping and visualization improvement of their projects.
At this point, the reader can realize that the teaching site is a guide where students can find the basic elements needed for a civil engineering project VR presentation. With this information, students can find ideas and utilize the modules in developing their projects.

Component 7: Teaching Resources

The last component shown in Figure 2 is a Teaching Resource repository containing research papers related to VR, XR, AR, and engineering education. These papers are mainly summarized in Section 2 of this paper. Universal Design for Learning (UDL) resources related to XR (url20, url21, url22) are also included. XR technology is considered a powerful tool for students because it can keep students with Learning Disabilities (LD) motivated. Material from our institution's VR/gaming development experts (url23, url24) is also included in this final module.

Discussions on VR Module Development

We will now discuss the development of the VR learning site, its benefits, and its challenges. It took around three months to build the module, dedicating 10 hours per week to its development. The main developer is a civil engineering Ph.D. student with a background in structural design (9 years academic, 17 years practicing) and no background in VR game development. The student's only experience with VR was in the Fall semester of 2019, where he developed a VR experience in a Dynamics graduate course in a group with three classmates. Thus, the developer had some experience with the Unity VR environment. The instructor and the Ph.D. student have weekly meetings to discuss questions and the direction and components of the development.

The most significant benefit of the XR training site is that the site is modular and can fit any course in any engineering department. Furthermore, the links are disclosed so one can quickly adapt and replicate a similar site at other institutions.

The site's development found some challenges, like the lack of VR-supported education-focused examples oriented to Civil Engineering applications. Despite there being great examples of research related to the application of VR in civil engineering education [12], [13], [14], [15], [16], [17], [18], the VR model files or final product visualization shown in these papers are not available to the public. An open-source national AR/VR courseware repository would be a great resource, but that is currently unavailable.

The video tutorials found online are based on multiple versions of Unity, but they are not updated when a new version of Unity is released, putting the site at risk of being out-of-date as the technology is quickly evolving. Additionally, as mentioned earlier, hardware is constantly evolving and becoming more affordable; however, the hardware available in the laboratory (HTC VIVE) is discontinued, and their support in Unity and other software will also be discontinued in the future.

The compatibility of Unity with commercial proprietary software was not tested because of the availability of these programs to the site developer. Big engineering software companies (Autodesk, https://www.autodesk.com/solutions/extended-reality, Trimble, https://www.sketchup.com) have their own expensive VR products, and in some cases, these products are not accessible to students through educational license agreements. Companies encourage the use of their products as total design/modeling/visualization solutions.

5 IMPLEMENTATION: SENIOR DESIGN

As discussed, XR technology can be implemented in any Civil Engineering course, and literature proves the effectiveness of XR technology in laboratory courses, construction engineering projects, and other courses. Therefore, it is recommended that instructors optimize XR technology for their courses.

In this paper, the instructors implemented XR technology in senior-level capstone project courses. At the University of Connecticut, the project course spans two semesters. Students form a team with three to four students and work with a faculty advisor and an industry mentor to complete a professional capstone project. Students complete their proposal in the first semester and develop their final deliverables during the second semester. Final deliverables include the project outcome, alternatives, and a report and presentation.

The hypothesis is whether the AR/VR technology increases students' motivation for the project and improves their comprehension of the design process. Among five sections of the capstone design course, three sections are comparison groups, and two are experimental groups. The experimental groups consist of two instructors teaching nine teams: five teams for Construction and Site Design and four for Structural Engineering. In their final presentation, these students are recommended to develop an AR/VR model of their final deliverable and present their design as an AR/VR model. The developed AR/VR laboratory, XR training site, and all the tutorials will be used for the self-learning of these students. In addition, the same Ph.D. student previously discussed utilized 50% of the 10 hours dedicated to this work to hold office hours and mentor senior students to build their models. The three comparison groups are not exposed to AR/VR technology.

The students in the experimental groups have access to the laboratory and the XR training site, and an introductory presentation has been given. Because the XR technology will be used as the final assessment, only formative assessment is planned at the end of the Spring 2022 semester. The Student Evaluation of Teaching and additional open-ended questions about AR/VR will be also available at the end of Spring 2022 semester. The initial assessment results will be reported at the annual conference.

6 CONCLUSION

A modular online training site was developed for Civil Engineering students, which can be used for any course in any department. With this resource, students can learn by themselves how to develop VR models. The pilot study was designed, and the implementation and assessment are underway, with CE senior students developing a VR presentation as part of their Senior Design final project deliverables. The anticipated result is that the AR/VR training module will improve senior students' 3D visualization skills and self-efficacy. Additionally, it is expected that using VR tools to create their final project presentation will increase their motivation and engagement. This study has an expandability potential. Therefore it can be implemented in any school with a low cost of implementation.

REFERENCES

[1] Radianti, J., Majchrzak, T. A., Fromm, J., Wohlgenannt, I. (2020). *A systematic review of immersive virtual reality applications for higher education: Design elements, lessons learned, and research agenda*. Computers & Education. https://doi.org/10.1016/j.compedu.2019.103778

[2] Merchant, Z., Goetz, E. T., Cifuentes, L., Keeney-Kennicutt, W., & Davis, T. J. (2014). *Effectiveness of virtual reality-based instruction on students' learning outcomes in k-12 and*

higher education: A meta-analysis. Computers & Education, 70, 29–40. http://dx.doi.org/10.1016/j.compedu.2013.07.033.

[3] Wang, P., Wu, P., Wang, J., Chi, H.-L., & Wang, X. (2018). *A critical review of the use of virtual reality in construction engineering education and training*. International Journal of Environmental Research and Public Health, 15(6), 1204. doi:10.3390/ijerph15061204

[4] Meta Platforms Inc. (2021). Introducing Meta: A social Technology Company. https://about.fb.com/news/2021/10/facebook-company-is-now-meta/

[5] ReportLinker (2021). Virtual Reality (VR) Market – Growth, Trends, COVID-19 Impact, and Forecasts (20-2026). https://www.reportlinker.com/p06184936/Virtual-Reality-VR-Market-Growth-Trends-COVID-19-Impact-and-Forecasts.html?utm_source=GNW. Accessed 01/11/2022.

[6] Castronova, E. (2001). *Virtual worlds: a first-hand account of market and society in the cyberian frontier*. CESifo Working Paper No. 618. Center for Economic Studies & Ifo Institute for Economic Research, Munich Germany. ISSN 1617-9595.

[7] Chavez, B., & Bayona, S. (2018). *Virtual reality in the learning process*. In Trends and advances in information systems and technologies (pp. 1345–1356). Springer International Publishing. https://doi.org/10.1007/978-3-319-77712-2_129

[8] Feng, Z., González, V. A., Amor, R., Lovreglio, R., & Cabrera-Guerrero, G. (2018). *Immersive virtual reality serious games for evacuation training and research: A systematic literature review.* Computers & Education, 127, 252–266. https://doi.org/10.1016/j.compedu.2018.09.002

[9] Jensen, L., & Konradsen, F. (2018). A review of the use of virtual reality head-mounted displays in education and training. Education and Information Technologies, 23(4), 1515–1529. http://dx.doi.org/10.1007/s10639-017-9676-0

[10] Suh, A., & Prophet, J. (2018). *The state of immersive technology research: A literature analysis*. Computers in Human Behavior, 86, 77–90. https://doi.org/10.1016/j.chb.2018.04.019

[11] Hain, A., Motaref, S. (2020). *Implementing Interactive 3-D Models in an Entry Level Engineering Course to Enhance Students' Visualization*. ASEE's Virtual Conference. June 22 – 26, 2020. 2020. American Society for Engineering Education, Papers on Engineering Education Repository. http://dx.doi.org/10.18260/1-2--34782

[12] Bao, H. (2015). *Hydraulic Engineering Visualization Simulation System Based on VR*. 2nd International Conference on Electrical, Computer Engineering and Electronics, ICECEE 2015. https://doi.org/10.2991/icecee-15.2015.304

[13] Hossain, M., Hanson, J. W., Moreu, F. (2021). Real-Time Theoretical and Experimental Dynamic Mode Shapes for Structural Analysis Using Augmented Reality. In Topics in Modal Analysis & Testing, Volume 8 (pp. 351-356). Springer, Cham. DOI:10.1007/978-3-030-47717-2_36

[14] Sampaio, A. Z., Henriques, P. G., Martins, O. P. (2010). *Virtual reality technology Used in civil Engineering Education*. The Open Virtual Reality Journal. Vol. 2, 18-25. DOI: 10.2174/1875323X01002010018

[15] Ren, S., McKenzie, F. D., Chaturvedi, S. K., Prabhakaran, R., Yoon, J., Katsioloudis, P. J., Garcia, H. (2015). *Design and Comparison of Immersive Interactive Learning and Instructional Techniques for 3D Virtual Laboratories*. Presence: Teleoperators and Virtual Environments; 24 (2): 93–112. https://doi.org/10.1162/PRES_a_00221

[16] Setareh, M., Bowman, D., Kalita, A., Gracey, M., Lucas, J. (2005). *Application of a Virtual Environment System in Building Sciences Education*. Journal of Architectural Engineering, ASCE. DOI: 10.1061/(ASCE)1076-0431(2005)11:4(165)
[17] Sun, Y., Chen, X., Huang, Z., Tao, D., Chen, L., Zhou, C., Liu, L., Zhou, Q. (2018). *Application of Virtual Reality Technique to Civil Engineering*. Advances in Computer Science Research, volume 86. International Symposium on Communication Engineering & Computer Science (CECS 2018).
[18] Wang, C., Tang, Y., Kassem, M. A., Li, H., Hua, B. (2021). *Application of VR technology in civil engineering education*. Computer Applications in Engineering Education. https://doi.org/10.1002/cae.22458