EPiC Series in Built Environment

Volume 5, 2024, Pages 84–92

Proceedings of 60th Annual Associated Schools of Construction International Conference

Use of Virtual Reality in Construction Higher Education in the US

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This study presents the state of Virtual Reality (VR) utilization by construction educators in the US. To gain insight into how educators use VR, a survey was conducted of educators affiliated with the Associated Schools of Construction. Survey responses indicated varying levels of familiarity with VR technology, with the majority exhibited diverse engagement levels, ranging from occasional to frequent use, highlighting VR's adaptability in construction education. The study delved into specific teaching areas where VR was employed, revealing "Methods, materials, and equipment for construction" as the most common application, with a quarter of participants using VR for this purpose. "Construction safety" closely followed, underlining its significance in safety education. In terms of technology and hardware, Head-Mounted Displays (HMDs) were the preferred choice, with Hololens being the most popular hardware among HMDs. These findings offer practical guidance for educators and program administrators seeking to maximize VR's role in construction education.

Key Words: Virtual reality, immersive environment, construction education, construction safety training, architectural education, technology integration in education

Introduction

Virtual reality (VR) is not a recent technology; it has been widely applied in medical education for close to two decades. However, its application in construction education is a more recent development. Many researchers and construction educators are now actively investigating the possibilities of integrating VR into construction education (Kim 2022) and they have found it to be helpful.

For instance, research has shown that game-based virtual environments, in comparison to traditional paper-based learning, are more effective for educating undergraduate construction students (Beh et al. 2022) VR has been found to be effective in stakeholder engagement, design support, design review, construction support, operations and maintenance (O&M) support communication, and more (Davila Delgado et al. 2020). The application of VR spans across several domains such as construction materials (Ghosh, Johnston, and Bigelow 2019), safety training, communication (Wen and Gheisari 2020b), construction sequencing (Lucas and Gajjar 2022), BIM coordination (Ghanem 2022), virtual field trip (Eiris Pereira and Gheisari 2019a), equipment operation training, and inspection (Beh et al. 2022).

While VR has been extensively studied by construction educators for specific applications, there is an absence of a comprehensive understanding of its current utilization in construction education. Apart from its industry applications, most reported uses involve experimental evaluations of VR's effectiveness and feasibility. In a literature review conducted by Wang et al. (2018), it was discovered that half of the selected publications primarily focused on VR applications in architectural visualization. Much of the available literature in construction education predominantly discusses VR's usage in evaluating BIM models or for safety and equipment operation training (refer to Figure 1). Strikingly, there is a scarcity of literature providing insight into how construction educators are presently integrating VR into the education of construction students. In summary, despite ample research available on the use of virtual reality in construction, there is a lack of clarity regarding its current adoption by construction educators. This research seeks to address this knowledge gap by exploring the following research question: *How are construction educators currently utilizing VR in their teaching practices?*

To answer the research question, a two-part approach was employed. First, a systematic literature review was conducted, and this was followed by a nationwide survey targeting educators in construction programs. The subsequent sections provide an overview of the literature review findings, followed by a detailed explanation of the survey methodology, and finally summarizing the results obtained from the survey responses.

Literature Review

For the systematic literature review, academic databases such as EBSCO, Web of Science, and ASCE (American Society of Civil Engineers) were used. Research publications were included if they had 'virtual reality' and 'construction' in their title or abstract, or if they contained any combination of 'virtual reality' with the following words: 'construction,' 'education,' or 'training' in the title or abstract. It was assumed that authors would use various combinations of these words when the article's focus was on the adoption or implementation of VR in construction education. Using these search criteria and including articles published from 2016 onwards, and excluding articles that were not related to construction education, a total of 44 articles were identified for this review. The articles revealed a wide range of research methods used by previous researchers such as literature reviews, intervention experiments, surveys, and similar. Notably, experiments were the most frequently employed method, with over half of existing studies incorporating some form of experimentation in conjunction with surveys as their research approach.

Regarding the various technologies explored in these articles, immersive VR, where the user's vision is entirely replaced by a digital environment, emerged as the most used technology for educational purposes. Augmented reality (AR) followed closely behind. In addition to immersive VR and AR, non-immersive VR technologies like screen-based games, VR Cave, and Building Information Modeling (BIM) were also employed (refer figure 2). The effectiveness of these immersive technologies in higher education settings were assessed across a variety of topical areas. Among all areas, safety training emerges as one of the most prevalent areas of utilization (23 articles). Within safety training, over one-third of the articles specifically focused on hazard identification training.

Mora-Serrano, Muñoz-La Rivera, and Valero (2021)reported positive effects on the learning experience and outcomes in this regard. However, there are comparatively fewer studies on safety training for heavy construction projects, such as roads, bridges, and dams. One such study conducted by Kim, Ahn, and Anderson (2021) found VR to be effective in teaching onsite hazards in road construction projects.

Construction means and methods follow safety education as the next most common area where VR has been applied (16 articles). Apart from that, VR technology has been explored in various educational contexts, including site inspection training (Beh et al. 2022), communication (Wen and Gheisari 2020b), construction sequencing (Lucas and Gajjar 2022), and coordination within Building Information Modeling (BIM) models, virtual field trips (Eiris Pereira and Gheisari 2019), and construction equipment operation. Notably, game-based virtual environments have demonstrated their effectiveness for training undergraduate construction students compared to traditional methods (Beh et al. 2022). Communication is another area where the applicability of VR has been tested. A review by Wen and Gheisari (2020b) underscored the effectiveness of VR in enhancing communication among stakeholders. Further, VR integration in construction higher education has ventured into augmented reality-based reviews, VR-based BIM visualization, drone flight training for building inspection, virtual field trips, and collecting user response data for research. For instance, Kandi et al. (2020) found immersive VR to be highly effective for design review compared to conventional 2D drawings.

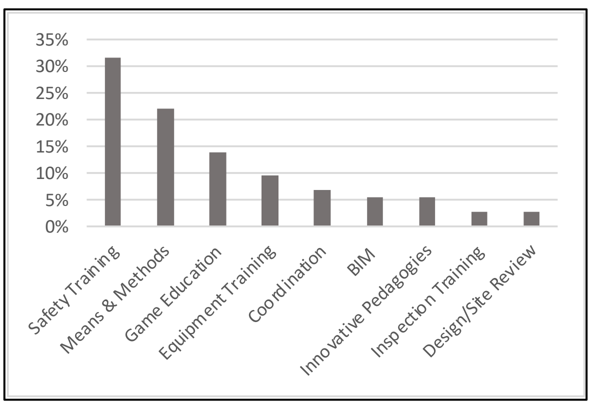

Figure 1.Distribution of areas considered for implementing immersive technologies

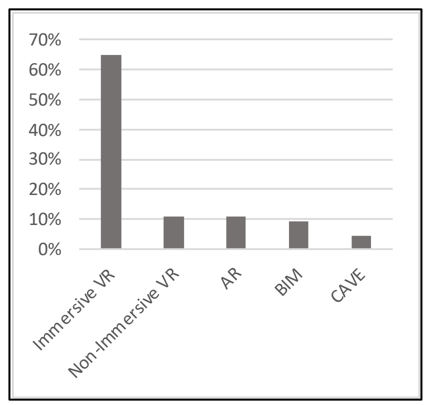

Figure 2. Distribution of papers discussing various immersive technologies

In the context of this study, Eiris Pereira and Gheisari (2019a) are among the very few who investigated the current state of utilizing VR. Their study specifically investigated the application of VR for virtual site visits in construction education. Further, there are very limited number of review articles on this topic, with Wang et al. (2018) and Ventura et al. (2022) being among the few, leaving the current state of integration of VR in construction higher education an unexplored area. While there are existing studies that have captured the specific utilization of VR on certain topical areas, an overall baseline understanding of the integration of VR in construction education curriculum has been unexplored. Subsequent to the literature review, a survey was conducted among current construction educators to fill in this gap.

Research Method

The objective of this study was to explore the current state of VR integration in construction education curriculum through descriptive research. This study focused on university faculty across the United States that are members of the Associated Schools of Construction (ASC). Within the overarching research question: *How are construction educators currently utilizing VR in their teaching practices?* this study specifically addresses the following questions:

- What is the level of familiarity among construction educators with VR technology?
- What are the primary uses of VR technology in construction education?
- Do construction educators employ VR technology for specific teaching areas?
- What types of technology and hardware do educators employ for utilizing VR technology in construction education?

This study employed a descriptive research design, which combines both quantitative and qualitative research methodologies to investigate "what is." Descriptive research utilizes observational and survey methods to collect data, providing insights into the variables and factors that influence the phenomena under study.

Sampling

The study targeted university faculty across the United States who are members of the ASC. The email list of the faculty from ASC was used for this purpose; the first email was sent during August 2023, followed by a reminder after two weeks. A priori analysis was conducted to determine the necessary sample size for the study, using the population proportion of a small finite population method. The required sample size was 87, but the survey garnered a total of 71 responses, falling short of the required size. A post-hoc calculation of the margin of error for the 71 responses resulted in a 12% ($\varepsilon = .12$) margin of error, slightly higher than the initially considered 10% for sample size estimation. This margin was deemed acceptable for the study since no inferential statistics were used to generalize the results.

Survey Instrument

To gather information about the current state of VR integration, a survey instrument was created. In two different sections, information to address research questions and participants' demographic information was collected. The first section has questions that gathered information about the use of VR. In the first question, educators were asked about their familiarity with VR. This question allowed us to direct the participants in two separate routes of survey. Participants who selected 'never used VR' were directed to watch an informative video about various uses of VR. This video was shown as we wanted to ask their opinion about the potential of VR in their teaching and research areas. After gathering their opinion about probable uses, the surveys for this specific group concluded with gathering general demographic information of the educators.

Educators who selected they 'use VR,' from low to high frequency, were directed to the second route. The initial question inquired about the applications for which they have used VR based on possible options reported in the existing literature (Davila Delgado et al. 2020; Eiris Pereira and Gheisari 2019; Wang et al. 2018). Considering that various technologies offer varying degrees of immersion in the virtual world, with head-mounted displays (HMDs) providing the highest level of immersion (Kim 2022), the subsequent question aimed to understand educators' preferences regarding immersive technology. This included choices between HMDs, Cave Automatic Virtual Environment (CAVE), and the use of 2-D screens. As the market offers various HMD models, the next question sought information about the specific HMD models in use. In the following question, educators were asked to specify the subject areas in which they currently utilize VR technology, as well as subject areas in which they believe VR technology has potential for future use. These subject areas were derived from the 'Standards and criteria for the accreditation of construction education programs' by the American Council for Construction Education (ACCE Current Documents, 2023).

The second section of the survey collected demographic information, including job title, highest degree attained, typical student demographics taught, and teaching areas. The survey was designed and distributed through the Qualtrics online survey platform.

Results

Data from Qualtrics online survey platform was exported; Microsoft Excel was used to sort the data and run descriptive analysis and create charts, and graphs presented below.

Participant's Demographics

A total of 71 responses were received out of which four were invalid, resulting in 67 valid, completed responses. Out of that, 56 responded to the job title-related question. Associate Professors (n=19, 28%) and Full Professors (n=17, 25%) formed more than 50% of the total participants. 10 (15%) participants were at the rank of Assistant Professor, whereas another 10 (15%) were either Renewable term/Adjunct/Visiting Faculty, and 11 (16%) participants did not report their ranks. Regarding the academic levels of the students taught by the participants, two participants exclusively taught graduate students, 25 (37%) exclusively taught undergraduate students, and 20 (30%) taught both graduate and undergraduate students. Participants were requested to report the subject areas they commonly teach. The subject areas covered by the participants were wide-ranging. As shown in Figure 3, the most frequently taught subject areas were BIM/VDC [24 (36%)], followed by construction project management [18 (27%)], and construction materials and methods [17 (25%)].

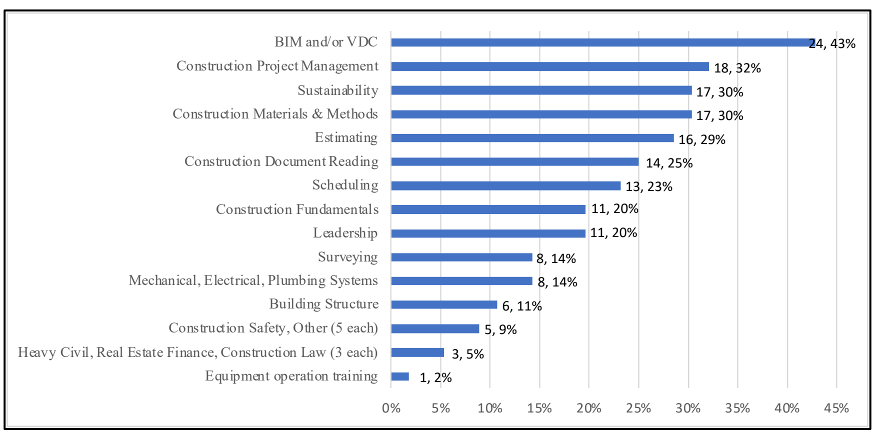

Figure 3. Subject areas taught by the participants

Current State of Use of VR

To measure the familiarity of the participants with VR, they were asked how frequently they use VR for their work. Out of the 67 valid responses, there were two individuals (approximately 3%) who stated that they had never used or heard of VR. Within the Full Professors category, over 80% reported rare (few times a year) or no usage of VR (refer to Figure 4). Conversely, 60% of Assistant Professors and 47% of Associate Professors mentioned using VR either every week or a few times a month. The group comprising Renewable Term/Adjunct/Visiting faculty exhibited a more diverse pattern – 21% reported frequent VR use (every week), while another 21% had never used VR (Figure 4).

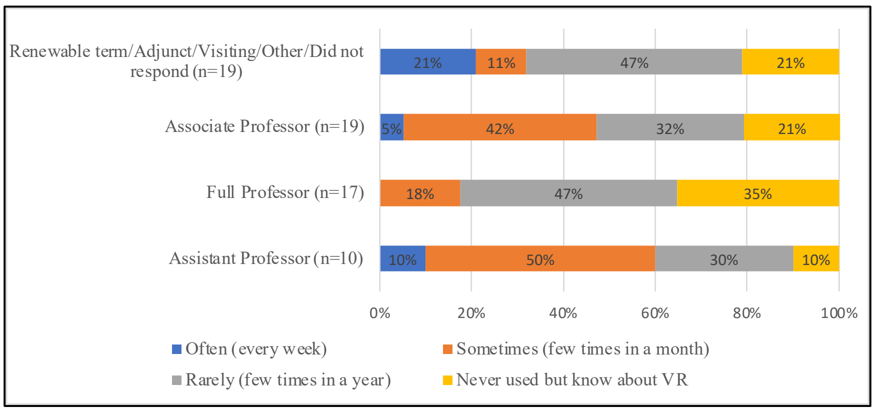

Figure 4. Frequency of use of VR by the participants

Regarding the purposes for which the participants employed VR technology, more than 40% (29) of the participants reported using VR for teaching or delivering course content to enhance the learning experience for students. Additionally, one-third of the participants (22) noted that they employed VR for research purposes. This suggests that educators saw the potential of VR in facilitating enhancing their research efforts, referring to integration of VR beyond traditional classroom instruction. A smaller subset of participants, approximately five participants (7%), mentioned alternative applications for VR in education. These applications included "showing students what it is," "for students' presentations," and "to show walk-throughs of lab renovations for donors" that have been combined under the “other” category. Figure 5 illustrates that instructors not teaching BIM or related courses tended to use VR more for research, virtual field trips, and virtual meetings, showcasing the diverse and creative incorporation of VR across various educational aspects.

Regarding the technologies that provide immersion in virtual environments, participants identified Head-Mounted Displays (HMD) as the most prevalent option, with 39 participants (61%) indicating its use (Figure 6). Following HMD, 18 participants (29%) reported employing 2D screens for this purpose. CAVE is the least used environment with only three (4%) participants mentioning about it. In HMDs, ‘Hololens’ [21 (33%)] was the most used hardware followed by ‘Meta Quest’ [11 (17%)] and ‘HTC Vive’ [7 (11%)] (Figure 6).

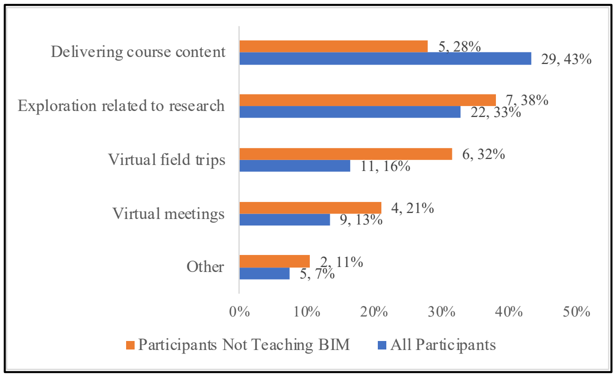

Figure 5. Purpose of VR use by participants

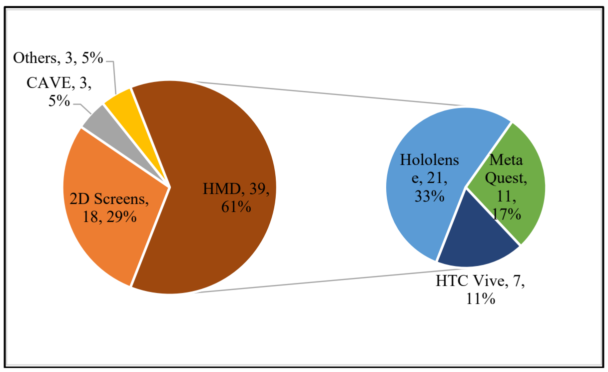

Figure 6. Technologies used for VR environment

Participants were inquired about current utilization of VR in their teaching (Figure 7). The responses revealed that "Methods, materials, and equipment for construction" was the most common subject area where VR was employed, with about quarter of the participants (17) using it. "Construction safety" closely followed, with 15 participants (22%) utilizing VR for teaching this subject area. In contrast, subjects like "Structural behavior of built structures," "Project cost estimation," and "Sustainable construction" each had fewer instances of VR utilization, ranging from three to five participants. These results suggest that VR is predominantly integrated into subject areas related to construction methods, materials, equipment, and safety, while other academic areas receive comparatively less emphasis regarding VR implementation in teaching.

Participants were also asked to identify the subject areas where they envisioned VR could be implemented in the future (Figure 7). It is important to note that while these responses provide insights into future trends, they may also reflect individual participants' optimism and personal biases, which could not be controlled. Considering the subject areas with the highest perceived potential for future VR integration, with more than one-third of the participants, 25 (37%), identified "Structural behavior for built structures." Currently this subject area is among the ones where fewer participants are implementing VR. Following closely were "sustainable construction" and "MEP," each with 22 and 21 mentions (9%), respectively. The remaining subject areas had similar occurrences, contributing to 6-7% of responses.

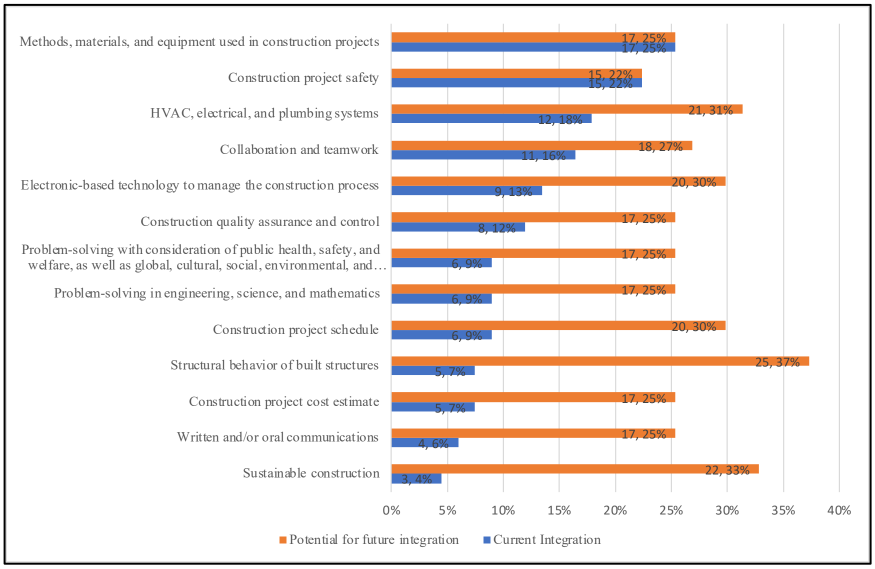

Figure 7. Current integration and future potential for VR integration

Conclusions

This study aimed to provide a comprehensive understanding of the current utilization of VR by construction educators in the United States. While VR has been the subject of numerous studies in specific applications within construction education, there was a notable gap in understanding its overall adoption among construction educators. The research addressed four key research questions, shedding light on the state of VR usage in this context. Data was collected through an online survey of the construction educators who are members of ASC. The subsequent analysis of the collected data, primarily consisting of descriptive statistics, helped to address the research questions.

The responses revealed a range of familiarity with VR technology among participants. While 21% of the respondents had never used VR, the majority exhibited diverse levels of engagement. The participants' utilization of VR ranged from occasional usage to weekly and even several times a week. This diversity reflects the adaptability and varied applications of VR technology in the field of construction education. The educational applications of VR were equally diverse. More than 40% of participants employed VR for teaching and delivering course content, emphasizing its potential for enhancing the learning experience. Furthermore, one-third of the participants recognized VR's value for research purposes, extending its utility beyond traditional classroom instruction. Nearly one-third also reported using VR in engaging students in innovative ways.

The study delved into specific teaching areas where VR was employed. "Methods, materials, and equipment for construction" emerged as the most common subject area, with a quarter of the participants utilizing VR for this purpose. "Construction safety" closely followed, indicating its importance in enhancing safety education. In contrast, subjects like "Structural behavior of built structures," "Project cost estimation," and "Sustainable construction" saw fewer instances of VR integration, highlighting potential areas for growth and development. Predicting the trend for the future, participants envisioned the greatest potential for VR integration in the subject area of "Structural behavior for built structures." This was particularly noteworthy, as it was among the areas with limited current VR implementation, suggesting room for future expansion. Additionally, subjects like "Sustainable construction" and "MEP" were identified as having substantial potential for VR adoption.

Regarding the types of technology and hardware used, Head-Mounted Displays (HMD) emerged as the most popular choice, favored by most participants. Hololens was the most frequently used hardware among HMDs. While VR technology is evolving rapidly, the preference for HMDs in this study showcases their practicality and effectiveness for construction education.

In summary, this research provides valuable insights into the current state of VR utilization among construction educators, revealing the diverse applications and the potential for further growth in enhancing construction education through VR technology. The findings have practical implications for both educators and program administrators looking to harness the full potential of VR in construction education.

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