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Immersive Virtual Field Trips with Virtual Reality in Construction Education: A Pilot Study

Yupeng Luo, Ph.D., Wei Wu, Ph.D., Gustavo Morales, and Elnaz Mohammadiyaghini, M.S.
California State University, Fresno
Fresno, California

Field trips or site visits provide valuable learning opportunities in construction education. However, traditional field trips often face challenges such as accessibility, logistics, weather, safety, to name a few. The recent global pandemic and its stipulations on social distancing add another layer of complexity to implement. Alternative field trips such as virtual field trips (VFTs), which are usually enabled by technology innovations, can help overcome these barriers. Previous VFT researchers shared promising results in providing a rich learning experience to students while also noting the lack of robustness and immersiveness. This study aims to develop a prototype of an immersive VFT solution with virtual reality (VR) to facilitate field knowledge transfer in construction education. The paper presents the VFT development process and shares preliminary results of student learning and user experience data from the first prototype. Findings of this pilot study suggest that a key advantage of VFTs over traditional field trips resides in the opportunity of learning iteration, which is essential to successful knowledge acquisition in the cognitive learning domain. The preliminary analysis on the correlation between student performance and media types of information also provides insights into future VFT design based on the multimedia learning framework.

Key Words: Virtual Field Trip, Construction, Virtual Reality, Immersiveness

Introduction

Field trips to actual project sites form an important component in teaching and learning in many aspects of construction management and civil engineering education (Wilkins & Barrett, 2000). They provide students with real-world experience and valuable exposure to the context to which their technical knowledge gained from classroom learning can be applied. Field trips also help bridge formal and informal learning and prepare students for lifelong learning (Tuthill & Klemm, 2002). However, scheduling and access difficulties may make actual field trips impossible to organize. In addition, organizers need to consider job site safety, transportation, weather, and other logistics challenges (Wilkins & Barrett, 2000; Pham et al., 2018). The emerging health risks under the COVID-19 pandemic have significantly limited field trips' viability.

Research literature suggests that scholars have investigated virtual field trips (VFTs) using videos and other traditional media as alternatives and indicated encouraging outcomes in student learning (Wilkins & Barrett, 2000; Tuthill & Klemm, 2002; Haque et al., 2005; Jaselskis et al., 2010). Compared with physical field trips, VFTs have advantages in flexibility and accessibility but lack robustness and immersiveness (Spicer & Stratford, 2001). Recent advancement in construction information and visualization technology such as building information modeling (BIM) and virtual reality (VR) enables a new genre of VFTs, featuring a digital twin (the digital representation) of the physical project to construct an immersive learning environment where students can obtain valuable field knowledge even with social distancing.

This study aims to develop a prototype of a new VFT solution, distributed via an off-the-shelf online VR platform to facilitate field knowledge transfer in construction education. This is an area that has not been addressed in available VR platforms used for education and training purposes, and has the potential to bridge the equity gap in future education. The proposed VFT prototype consists of field-captured 360-degree photos and other project information obtained with permission from partnering construction and engineering companies. Students can access this VFT prototype via a designated VR platform and experience a self-guided or guided immersive tour with low-cost VR headsets. This paper presents the preliminary findings of the research, which includes the design of the first VFT prototype and results from the initial learning assessments and user experience evaluation.

Background and Literature Review

A VFT in construction education refers to an experience of observing the physical conditions of a construction project via the Internet or other technologies (Finch & Wing, 1996; Jaselskis et al., 2010). As an alternative, it has the potential of offering similar benefits of a traditional field trip without the associated barriers. Previous studies on construction related VFT or VR applications explored a wide range of learning outcomes. Many intended to help students in introductory courses gain a general understanding of their disciplines. These VFTs usually included "random activities, structures, and operations on construction job sites" (Wen & Gheisari, 2020; Finch & Wing, 1996; Mei & Wing, 1999; Wilkins & Barrett, 2000; Dickinson et al., 2004; Jaselskis et al., 2010; Landorf & Ward, 2017; Zhang et al., 2017; Maghool et al., 2018; Quinn et al., 2019). However, some studies took a more focused approach to address specific learning outcomes, such as reinforced concrete construction (Haque et al., 2005), heating, ventilation, and air conditioning (HVAC) systems (Shen et al., 2012), construction safety (Zhao & Lucas, 2014, Pham et al., 2018); structural deformation modes (Fogarty et al., 2018), wood-framed construction techniques (Lucas, 2018), etc. Such VFTs may require more efforts in site selection and tour design to ensure activities are tied to the specific learning outcomes (Wen & Gheisari, 2020).

Despite the fact that early VFTs demonstrated to be a good and enjoyable way to learn, studies also noted their lack of robustness and immersiveness compared to real field trips (Spicer & Stratford, 2001). The recent advancement in computer graphics and visualization and the uprising of cloud computing technology has brought unprecedented learning affordance to higher education, which holds the promise to revitalize the application of VFTs. Wen and Gheisari (2020) classified the technologies used in current construction-related VFTs into two categories: captured-reality technology and virtual reality (VR) technology. The captured-reality technology uses regular or 360-degree images or videos of real-world projects, while the VR technology uses computer-generated simulations of reality (e.g. 3D models). Both have their advantages and limitations. Images and videos offer the highest level of realism but limited interactions with the site due to the fact they are precaptured or delivered in real-time. On the other hand, a simulated environment gives an instructor full control of learning activity design and allows students to navigate a site freely, which potentially leads to a more active learning experience. However, the limited sense-of-realism and level of details could also prevent students from fully understanding the complexity and context of real-world practices (Wen & Gheisari, 2020).

Research Design

The long-term goal of this research is to develop an enhanced immersive VFT solution to facilitate field knowledge transfer in construction education using both reality-capturing technology and VR technology. Individual VFTs will be constructed with a mixed-use of 2D plans, 3D asset models (imported from mainstream 3D information modeling applications such as Autodesk Revit and Trimble SketchUp), regular or 360-degree images or videos, audio recordings, PDF documents, etc. User activities in this virtual space can be inquiry-based or problem-based to address a wide spectrum of knowledge acquisition or skill development, including 3D spatial exploration and reasoning, design review and communication, code compliance, construction operations, safety, sustainability, etc.

As noted in Mayer's cognitive theory of multimedia learning (2002), humans use a visual/pictorial channel and an auditory/verbal-processing channel for information processing. To optimize learning, it is important to apply effective design strategies to manage cognitive load in multimedia learning materials so the channels are not exceeding their limited capacity. Brame (2016) summarized four best practices to manage cognitive load for educational videos: signaling (to highlight important information), segmenting (to chunk information), weeding (to eliminate extraneous information); and matching modality (by using appropriate channels to convey information). These recommendations were considered during the VFT design in this study.

The team developed the first VFT prototype to investigate two research questions: (1) Can VFTs create a learning environment with sufficient information for students to learn technical knowledge in construction? and (2) How do students respond to this new genre of immersive virtual learning environments? A phased approach was adopted in developing the pilot study as elaborated below:

1. Platform Selection: The team envisions the proposed VFTs to be distributed via a cloud-based open VR platform that supports multimedia and integration with commonly used project design and management tools. To ensure flexibility and affordability, a suitable platform would support not only mainstream VR equipment (e.g., HTC Vive, Vive Pro, Cosmos; Oculus Rift/Go/Quest, Google Cardboard, etc.), but also web browsing on any device. After reviewing a number of available VR platforms such as Unity, Second Life, Sansar, HoloBuilder, Cupix, OpenSpace, etc., the team chose HoloBuilder due to the aforementioned desirable features. This platform is typically used by construction professionals for jobsite progress management by creating a digital replica of their sites.
2. Project Data Collection: To test various features in a VFT, several local projects were identified to address different learning outcomes in early prototypes. A recently completed university research laboratory building was selected as the site for the first VFT prototype. The team obtained a full set of 2D plans and specifications, a Revit 3D model, and a building maintenance manual from the university. In addition, the team arranged multiple guided tours to document the building with 360-degree images using an Insta360 One X camera.
3. Prototype Design and Development: When it comes to the planning of an educational tour (virtual or in-person), it is always helpful for the organizer (or the tour guide) to review the following questions: Who are the audience, what should they learn, and how long is the tour? The first VFT prototype was designed to demonstrate a guided virtual tour of a university laboratory

building. VFTs like this one simulate traditional field trips for students in introductory architecture, engineering, and construction (AEC) courses. The prototype addresses specific topics related to the following two areas:

- Architectural and Structural Design: This includes the building's sustainability/energy performance goals, the structural frame of the building, the composition of the architectural precast concrete wall panels, the glazing system, the difference in design considerations between a dry lab and a wet lab, etc.
- Facility Management: This includes the handling of various chemicals, the unique water infiltration system utilized in this building, etc.

The length of a VFT can also have an impact on learning due to its multimedia nature. On one hand, some users may experience VR sickness after an extended period in an immersive VR environment. On the other hand, studies of multimedia learning have shown that educational videos less than 6 minutes long have a median student engagement rate of 100%. The rate drops to 50% for 9- to12-min videos and even more significantly for longer videos (Guo et al., 2014; Brame, 2016). Keeping VFTs short may help decrease mind wandering and therefore increase student attention to content.

4. Assessment: This study adopted a mixed-methods approach by combining quantitative and qualitative assessments in a post-test survey (available upon request). The intent was to measure the effectiveness of the VFT prototype on learning and gauge students' perception towards this new learning experience.

Results and Findings

Figure 1 provides a sample view of the first VFT prototype. A floor plan is displayed on the top left corner with small circles called "waypoints". Each waypoint is linked to a 360-degree image (i.e., a scene) in the VFT. When a user is viewing a scene, the corresponding waypoint will be highlighted on the floor map indicating where it is located.

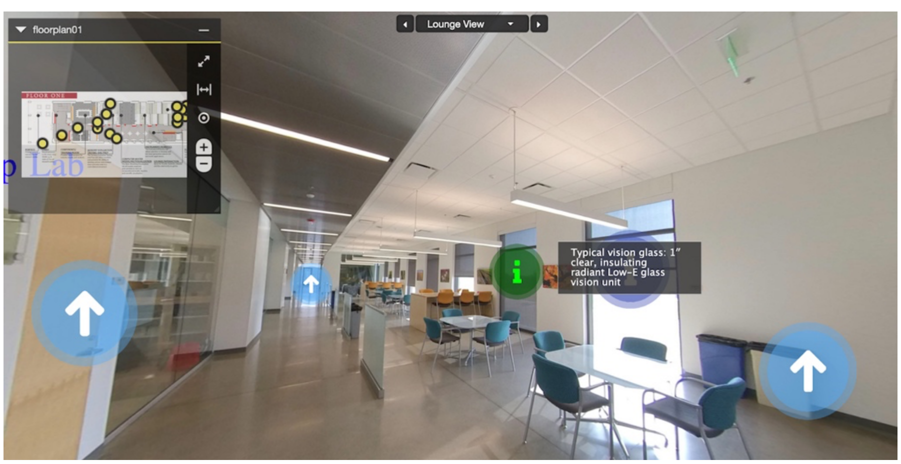

Figure 1. A sample view of the first VFT prototype

In a traditional field trip, a tour guide would stop at multiple locations to discuss specific topics. In a VFT, these stops are called "hotspots". Throughout a tour one will have the opportunity to stop at many hotspots to make observations and interact with various "action objects", meaning special actions will be triggered when a user clicks on or hovers over them. As a result, new content will display, which can be an embedded video, an audio clip, quick text, a 2D image, another 360-degree scene, a PDF file, etc.

A total of 33 construction management (CM) undergraduate students from two introductory CM courses participated in the pilot test of the proposed VFT prototype. Of these participants, 24 (73%) were male and 9 (27%) were female. The average age of the group was 22.4 years old (range = 19-35 years). The majority held junior (39.4%) or freshman (30.3%) class standing. In regard to ethnicity, Hispanic ranked the highest (67%), followed by White (15%) and Asian (12%). The pilot test consisted of simple navigation activities, interaction with building elements and systems, review of project documentation, and completing a simple assessment quiz. The quiz was designed with two parts: Part 1, i.e., Questions 1-8 checked on students' technical knowledge in design and facility management; Part 2, i.e., Questions 9-10 solicited students' feedback on the experience of using the VFT prototype, including the ease of navigation, discovery and information query, and other cognitive explorations. The technical questions in Part 1 are project-specific, which students would not have had prior knowledge of. Therefore, there was no pre-test.

Compared with the instantaneous nature of conventional field trips, an advantage of the VFT is the ability to allow students to revisit and repeat certain activities to facilitate the acquisition of a specific area of knowledge, and/or reinforce knowledge gains via such iteration. According to Holmes et al. (2015) and Corwin et al. (2018), iteration plays an important role in cognitive learning in knowledge acquisition and critical thinking development. In this pilot test, students were encouraged to take the assessment quiz multiple times (the highest grades among these attempts would count as their final score of the quiz) until they felt satisfied with the results, which was aligned with the tenet of competency-based learning. Among the 33 participants, 23 students attempted the quiz twice, 8 students attempted 3 times, and 1 student took it 4 times (this student had already achieved 100% at Attempt 3, so Attempt 4 was redundant and removed from analysis). Table 1 lists the specific technical area(s) each question addresses, how the information was presented, and the percentages of correct answers after each attempt. The percentage of correct answers after each attempt is calculated as the accumulative number of students who answered the question correctly by then divided by the total number of the participants (33). An improvement in percentages over the three attempts can be observed for all questions except Question 5 (where students who answered it wrong did not make more than one attempt) and Question 8 (where no one answered it wrong). Table 2 summarizes the assessment efforts, results at each attempt, and the final results. The average score (arithmetic mean) of Part 1 (Questions 1-8) for the entire group went up from 80.7% of Attempt 1 to 93.9% of Attempt 2, and 96.2% of Attempts 3, which was also the final cohort average score. A total of 25 students finished the quiz with 100.0%, with 7 of the rest students having 87.5%, and 1 student having 75%. The assessment target was set to have more than 80% of the group to score an average of 75% or higher, which was already met in the first attempt (87.9%).

Table 1

Percentages of correct answers after attempt 1, 2, and 3 for Questions 1-8

Question	Tech. Area (Design/FM)	Format of Info.	% After Attempt 1	% After Attempt 2	% After Attempt 3
1	Design	Quick Text	78.8	100	100
2	Design	2D Image	93.9	97.0	100
3	Design	Quick Text	90.9	100	100
4	Design & FM	2D Image	97.0	97.0	100
5	Design	2D Image, 360 Scene	97.0	97.0	97.0
6	FM	PDF, 2D Image	18.2	84.9	84.9
7	Design	2D Image	72.7	75.8	87.9
8	FM	PDF, 360 Scene	100	100	100

Table 2

Student attempts and scores of Part 1 of the assessment quiz

Description	Attempt 1	Attempt 2	Attempt 3	Final
No. of Students	33	23	8	33
Part 1 Average Score (%) (For the entire group of 33 students)	80.7	93.9	96.2	96.2
% Improvement Compared with Attempt 1	N/A	15.4%	18.5%	18.5%
Assessment Target (>80% of the group with 75% average score or better)	87.9%	100%	100%	100%

The most important takeaway from the analysis of students' performance in the assessment quiz was not the score (%) or its distribution, but the apparent improvement of students' performance via iterative learning using the VFT, and the engagement demonstrated via repetitive attempts made by a substantial number of students (23 out of 33, or 69.7%) in taking the quiz more than once.

To further understand students' experience and perception of the VFT prototype, Part 2 (Questions 9-10) of the assessment quiz requested students to reflect on perceived ease of conducting the virtual field, and the efficiency (i.e., how much time) and effectiveness (i.e., how useful) of the VFT experience in supporting them with necessary information needed to complete the assessment quiz. Students were also asked to suggest anything that could be improved to enhance their experience. Among the 33 students, only 3 (9.1%) students indicated some challenges of navigation through the virtual tour. The majority found the virtual tour intuitive and easy to follow through. Immersiveness was constantly brought up as a big excitement to engage them in the tour.

By diving into students' description of their tour experience and reasons for spending a specific amount of time on the tour revealed some additional insights into how students respond to the VFT prototype, and how this trip prepared them for the assessment. First and foremost, compared with the time typically spent on conventional field trips (e.g., 1-2 hours on campus, 2-4 hours off campus), the amount of time necessary for students to gather sufficient information for the assessment via the VFT was significantly shorter. Another key takeaway was that 29 out of the 33 students indicated the need to revisit the VFT to confirm or verify information assessed in the quiz. This was nearly impossible in conventional field trips. Among these 29 students who revisited the VFT, they consistently suggested the value of location-based information that was provided via images and PDF documents, which greatly enhanced their understanding of the project in the proper context. Unlike the sense of time constraints and an urgency of moving on in a conventional field trip, the fact that VFTs allowed students to take their time to observe and digest location-based project data and embedded field knowledge seemed to be one of the key benefits of VFTs.

Recommendations given by students to improve the VFT prototype clustered into three categories: navigation, interaction, and content. Specifically, the feedback on navigation suggested that navigation was a little constrained and did not support walking freely, which was intrinsic to the platform used to host this VFT. For interaction, current activities supported mainly involved passive observation and pop-up prompts for information review. Some students found the interaction could be a little more robust to include voice-over, or markers to allow document markup or note-taking, or route planning. For content, students liked the embedded texts and linked PDF documents, but would prefer more multimedia content such as audio/video clips to provide more dynamic information about the project.

Discussion

The initial assessment results from the first VFT prototype provided valuable insights for future VFT developments. The assessment was conducted during the pandemic when the university moved almost all classes online. As a result, students were not provided with VR headsets during the assessment. However, they were very impressed with the level of immersiveness even though they were only viewing the tour via a web browser on their computers or mobile devices. This shows promise for immersive VFTs to reach a broader user group.

Students appeared to enjoy the convenience of repeating a VFT. Their improved performance over multiple attempts was a strong indicator of the need for repetitions. Another takeaway from this is the repetitions do not have to happen after the tour ends. Same or similar learning topics can be embedded in a VFT at multiple locations and presented via different multimedia types to reinforce knowledge. The area students had to tour in the first VFT prototype was about 10,000 SF. Most of them were able to gather sufficient information for the assessment within 20 min. Not all virtual tours are easy to navigate. Setting a clear path on the floor map and focusing on the intended learning outcomes are essential. As discussed earlier, for a multimedia learning experience, keeping it short may help decrease mind wandering and increase attention to content. Incorporating interactive features (e.g., voice-over, measuring, document markups, etc.) and different multimedia content will create a richer and more engaging learning environment.

Some challenges and limitations were noted during the development of the first VFT prototype. The team initially intended to take advantage of the SplitScreen feature on HoloBuilder which allows users to compare design (3D model) with reality (field images), or project progress images side by side. This is difficult to realize in a traditional field trip, but in a VFT it is doable and opens up new learning opportunities. However, the lack of details in the builder's 3D model made it unsuitable for the virtual tour. It should also be noted that this is not uncommon. The levels of development (LOD) in BIM vary from 100 to 500 with LOD 500 being the highest level of accuracy ("as-built"). As-built models are generally requested by clients as reference for operation and maintenance. Yet for contractors LOD 350 is sufficient for construction documentation. Knowing what types of 3D models are available on a project helps determine the design limitations for a VFT.

The first VFT prototype was also limited on the variety of multimedia content as it did not incorporate any audio or video clips, which are features the team started to explore later while documenting active construction sites.

Conclusions

This study proposes an enhanced immersive VFT solution to facilitate field knowledge transfer in construction education using both reality-capturing technology and VR technology, an area that has not been actively explored in available VR platforms. A pilot study was conducted to develop a VFT prototype on HoloBuilder and collect preliminary results on student learning and user experience. The first VFT was designed to demonstrate a guided virtual tour of a university laboratory building and specifically address architectural/structural design and facility management topics. Information was presented via field-captured 360-degree images, regular 2D images, quick text, and PDFs. According to the post-test survey, the majority of the participants found the virtual tour easy to follow through and greatly enjoyed the immersiveness. Site revisits and multiple attempts on the survey were allowed. Results indicate that the group was able to meet the assessment target in their first attempt. Furthermore, results from multiple attempts suggest that allowing students to revisit and repeat certain activities facilitates the acquisition of a specific area of knowledge, and/or reinforce knowledge gains via such iteration.

While showing great potential, this first VFT prototype was limited on the variety of multimedia and active user interactions. The team is currently experimenting more interactive features and multimedia types and exploring effective learning design in an immersive virtual learning environment. Further research is needed to compare the effectiveness of the proposed VFTs with and without VR headsets.

References

Brame C. J. (2016). Effective educational videos: Principles and guidelines for maximizing student learning from video content. *CBE—Life Sciences Education*, *15*(4), es6.

Corwin, L. A., Runyon, C. R., Ghanem, E., Sandy, M., Clark, G., Palmer, G. C., Reichler, S., Rodenbusch, S. E., & Dolan, E. L. (2018). Effects of discovery, iteration, and collaboration in laboratory courses on undergraduates' research career intentions fully mediated by student ownership. *CBE—Life Sciences Education*, *17*(2), ar20.

Dickinson, I., Riley, A., Tennant, J., & Ellis R. C. T. (2004). Virtualsite: Photo-realism in the classroom. *COBRA 2004 Proceedings*.

Finch, E., & Wing, R. D. (1996). A navigable walkthrough simulator for built environment education: Archiwalk. *Facilities*.

Fogarty, J., McCormick J., & El-Tawil, S. (2018). Improving student understanding of complex spatial arrangements with virtual reality. *Journal of Professional Issues in Engineering Education and Practice, 144*(2), 04017013.

Guo P. J., Kim J., & Rubin, R. (2014). How video production affects student engagement: An empirical study of MOOC videos. In *Proceedings of the first ACM conference on Learning@ scale conference,* pp. 41-50.

Haque, M., Aluminiumwalla, M., & Saherwala, S. (2005). A virtual walkthrough on reinforced concrete construction details. In *2005 ASEE Annual Conference*, pp.10-108.

Holmes, N. G., Wieman, C. E., & Bonn, D. (2015). Teaching critical thinking. *Proceedings of National Academy of Sciences*, *112*(36), 11199-11204.

Jaselskis, E. J., Jahren, C. T., Jewell, P. G., Floyd, E., & Becker, T. C. (2010). Virtual construction project field trips using remote classroom technology. In *Construction Research Congress 2010: Innovation for Reshaping Construction Practice* (pp. 236-245).

Landorf, C., & Ward, S. (2017). The learning impact of a 4-dimensional digital construction learning environment. *International Journal of Social, Behavioral, Educational, Economic, Business and Industrial Engineering*, *11*(5), 1158-1163.

Lucas, J. D. (2018). Immersive VR in the construction classroom to increase student understanding of sequence, assembly, and space of wood frame construction. *Journal of Information Technology in Construction*, *23*, 179-194.

Maghool, S. A. H., Moeini, S. H. I., & Arefazar, Y. (2018). An educational application based on virtual reality technology for learning architectural details: challenges and benefits. *ArchNet-IJAR: International Journal of Architectural Research*, *12*(3), 246.

Mayer, R. E. (2002). Multimedia learning. *Psychology of learning and motivation*, *41*, pp. 85-139.

Mei, Q., & Wing, R. (1999). Robotic 360/spl deg/photography for virtual site visits. In *1999 IEEE International Conference on Information Visualization (Cat. No. PR00210)* (pp. 214-219). IEEE.

Pham, H. C., Dao, N., Pedro, A., Le, Q. T., Hussain, R., Cho, S., & Park, C.S.I.K. (2018). Virtual field trip for mobile construction safety education using 360-degree panoramic virtual reality. *International Journal of Engineering Education*, 34(4), 1174-1191.

Quinn, D., Cioffi, E., Hill, S., Kor, M., Longford, A. C., Moller, R., & Rathore, P. (2019). Implementing work-integrated learning in online construction management courses. *Journal of University Teaching and Learning Practice*, *16*(1), 9.

Shen, Z., Jiang, L., Grosskopf, K., & Berryman, C. (2012). Creating 3D web-based game environment using BIM models for virtual on-site visiting of building HVAC systems. *Proceedings of Construction Research Congress 2012: Construction Challenges in a Flat World* (pp. 1212-1221).

Spicer, J. I., & Stratford, J. (2001). Student perceptions of a virtual field trip to replace a real field trip. *Journal of Computer Assisted Learning*, *17*(4), 345-354.

Tuthill, G., & Klemm, E. B. (2002). Virtual field trips: alternatives to actual field trips. *International Journal of Instructional Media*, 29(4), 453-468.

Wen, J., & Gheisari, M. (2020). A review of virtual field trip applications in construction education. In *Construction Research Congress 2020: Safety, Workforce, and Education* (pp. 782-790). Reston, VA: American Society of Civil Engineers.

Wilkins, B., & Barrett, J. (2000). The virtual construction site: a web-based teaching/learning environment in construction technology. *Automation in Construction*, *10*(1), 169-179.

Zhang, C., Lu, Y., Xu, R., Ye, X., Shi, Y., & Lu, P. (2017). Educational tool based on virtual construction site visit game. *Modern Applied Science*, *11*(8), 47-56.

Zhao, D. & Lucas, J. (2015). Virtual reality simulation for construction safety promotion. *International journal of injury control and safety promotion*, *22*(1), pp. 57-67.