

A Virtual Site Visit on Four-Legged Robot Applications in Construction

Yuan Sun¹; Masoud Gheisari, Ph.D., A.M.ASCE²; and Idris Jeelani, Ph.D.³

¹Ph.D. Student, M.E. Rinker School of Construction Management, Univ. of Florida, Gainesville, FL. Email: yuansun@ufl.edu

²Associate Professor, M.E. Rinker School of Construction Management, Univ. of Florida, Gainesville, FL. Email: masoud@ufl.edu

³Assistant Professor, M.E. Rinker School of Construction Management, Univ. of Florida, Gainesville, FL. Email: idris.jeelani@ufl.edu

ABSTRACT

With the increasing deployment of robots in the construction industry, it is crucial for future professionals to not only be familiar with these robots but also understand their applications and associated safety challenges. However, the logistics and financial issues in bringing these robots to classes pose a challenge in including an effective robot-related curriculum in construction education. This study developed a virtual site visit that integrates virtual reality (VR) technology and immersive storytelling to expose students to a robot-dominant construction site. The virtual site visit enabled users to navigate a robot-dominant construction site and learn about four-legged robots, their applications, safety challenges, and countermeasures for working safely with robots. The results of the study demonstrate that virtual site visit offers unique opportunities for enhancing construction students' conceptual understanding of robots in diverse and unfamiliar scenarios without exposing them to undue risks or incurring substantial costs.

KEYWORDS: Four-legged Robot, Virtual Site Visit, Storytelling, Construction Education.

INTRODUCTION

The construction industry is increasingly adopting automation and robotics to address productivity and safety concerns. On-site robotic systems have proven effective in enhancing productivity by performing repetitive tasks such as bricklaying, finishing, and rebar-tying, enabling construction workers to focus on more complex tasks that require human skills and capabilities (Madsen, 2019). Furthermore, automation and robotics can help lower project costs by allowing construction work to continue during adverse weather conditions (Dakhli & Lafhaj, 2017; Iturralde et al., 2020). Additionally, construction robots can mitigate labor shortages and increase workforce access by enabling underrepresented groups of workers, such as disabled individuals who cannot perform heavy labor, to engage in construction tasks. Construction robots can also execute hazardous and labor-intensive tasks like demolition, reducing injuries and fatalities in an industry known for its dangerous work environment (Balzan et al., 2020). Therefore, it is crucial for construction students to learn about these new technologies to adapt to the future robot-dominated construction environment.

The current learning and training programs in the construction fields mainly rely on lecture-based learning and on-site visits (Adami et al., 2020). However, many of the lecture-based learning approaches operate under the implicit assumption that knowledge is easily transmittable. Consequently, these approaches are not always effective in enhancing learners' conceptual

understanding, particularly when dealing with unfamiliar situations, such as construction robots (Eiris, Jain, et al., 2020). Similarly, on-site visits are often used to provide students with opportunities to observe and operate robots in real construction environments (Eiris & Gheisari, 2018). Nonetheless, these training programs have significant drawbacks. They are often hazardous, time-intensive, and expensive due to the need for specialized equipment, maintenance costs, and experienced supervisors and assessors. As such, there is a need to explore alternative training and learning programs that can effectively enhance the conceptual understanding of construction students in unfamiliar situations, particularly construction robots, without exposing them to unnecessary risks or incurring high costs. This study explores the innovative use of a virtual site visit that integrates VR technology and immersive storytelling to expose students to virtual four-legged robots within a construction site. The aim of this study is to explore the use of the virtual site visit with immersive storytelling to support students in learning about four-legged robots, different applications that use such robots in construction, different safety challenges associated with them, and countermeasures for working safely with robots.

RELATED WORKS

Four-legged Robots in Construction. With the significant skilled labor shortage in the construction industry, the integration of robots in the construction work environment is inevitable. One type of robot that is becoming increasingly popular in the construction industry is the four-legged robot (also called quadruped robot), which offers ideal adaptability and mobility to work on a variety of construction applications (Bellicoso et al., 2018; Safeea & Neto, 2019). Four-legged robots are commonly used for monitoring and inspection activities. They have demonstrated the ability to traverse and scan the jobsite more frequently than humans, making the inspection and monitoring process more effective by generating digital replicas of the jobsites that can be used for manual or automated qualitative and quantitative assessments (Afsari et al., 2021; Halder et al., 2022). Furthermore, four-legged robots have been proposed for transporting material and tools on the jobsites, constructing building elements, and assisting in the building process (Bellicoso et al., 2018). The increasing deployment of four-legged robots in construction will result in increased interaction between human workers and such robots on the jobsite. Several studies have highlighted safety concerns regarding the rising interactions between humans and robots in shared workplaces. In general, these safety concerns could be classified into three categories: physical risks, attentional costs, and psychological impacts (Jeelani & Gheisari, 2021). Several measures have been developed to avoid these hazards or manage the risks posed by these robots. Morris & Cannady (2019) proposed that controls can be implemented to abate workplace hazards and protect construction workers. The first and most efficient action must be to attempt to eliminate the hazard completely to prevent major incidents or fatalities from occurring in the workplace. The second action is substitution or replacing a hazard source with something that does not pose a risk. The third strategy is engineering controls or isolating people from hazards that cannot be eliminated or replaced. For example, putting physical barriers (e.g., safety fence) around the workers who are working close to four-legged robots or barricading the area where robots are working. The next strategy is administrative control or changing the ways workers perform their tasks to minimize risk exposure. It means updating work procedures to accommodate robots while keeping workers safe. These include adding safety precautions or guidelines for workers to follow when working with or around robots. The last one is using appropriate Personal Protective Equipment (PPE), such as hard hats,

safety glasses, steel-toed shoes, and proper safety gloves while working with four-legged robots. Although much research on four-legged robots in construction has focused on their applications, safety challenges, and countermeasures, there is still a gap in delivering this knowledge to future construction professionals. Therefore, construction educators need to consider how to integrate the learning content involving such robotic technologies into the current construction curriculum so that students can adapt to future career development.

Virtual Site Visit in Construction Education. A multimedia simulation of a distant location that utilizes electronic devices to allow students to observe and interact with site-specific information is known as a virtual site visit (Eiris et al., 2020). VR, as one of the main methods depicting jobsites digitally, is defined as “a computer-generated three-dimensional environment in which users can manipulate objects, be immersed, and move around and see the environment from different angles” (Eiris et al., 2021). Virtual site visits have become a popular tool in aiding students' construction education due to their technological advantages. Such advantages enable students to become familiar with built environment disciplines, enhance their comprehension of building structures or materials, and improve their understanding of design review skills (Eiris et al., 2022; Kandi et al., 2020; Shen et al., 2012). In particular, Zhang et al. (2017) developed a virtual construction site where students could explore the virtual site freely and receive instant feedback. The result of this study showed that virtual site visits could enhance students' understanding of complicated structures, allow for better accessibility to more construction sites virtually, provide more convenient and flexible time for learning practices, and support safer site visits. In order to enhance students' critical thinking and communication abilities, Kandi et al. (2020) created a VR design-review game. As part of the experiment, the students were paired up and instructed to evaluate the design proposal of a sample building project. Considering the expensive cost and potential safety risks associated with placing four-legged robots on physical construction sites, virtual site visits were able to be used as an alternative to delivering the experience of using four-legged robots in the current construction curriculum.

Storytelling in Construction Education. Storytelling has been employed as a traditional method of education that is widely used as a teaching tool to convey knowledge, values, cultural beliefs, and traditions. Computer-based images, text, recorded audio, and video have typically been utilized to create digital stories (Collins, 2022; Eiris et al., 2021; Perry et al., 2018). Immersive storytelling has been used in several construction education and training programs. Wen & Gheisari (2021) developed An immersive 360-degree environment, utilizing virtual electricians to showcase success stories of electrical construction trades in the field, has been developed to encourage younger generations to consider joining the industry. Eiris et al. (2020) focused on using immersive storytelling within digital 360-degree panoramas to improve learners' hazard recognition and risk perception. The integration of virtual site visits and immersive storytelling provides significant benefits for accessing a realistic virtual environment and experiencing immersive stories on construction jobsites. Therefore, this study proposed a virtual site visit that incorporates learning contents related to four-legged robots technologies, applications, safety challenges, and countermeasures into a virtual site visit that includes VR technology and storytelling elements to provide a learning opportunity for students to learn about four-legged robots.

METHODS

This study introduces a virtual site visit platform that integrates virtual site visits and storytelling technologies to provide an opportunity for students to learn about four-legged robots

without exposing them to unnecessary risks and high costs. Two steps were taken to achieve this goal. First, the virtual site visit was developed using Unity® to provide intriguing stories that integrate four-legged robots into virtual construction sites. Then, an assessment survey was conducted to understand students' learning performance during the virtual site visit and to test the system's usability.

Virtual Site Visit Development. The development of the platform involves two main sections: narrative generation and technical development. To cover these training topics, a comprehensive review of four-legged robots and construction safety literature was conducted that included publications on four-legged robots' application in construction, the safety challenges that four-legged robots may introduce, and the countermeasures to address those safety concerns. Table 1 shows the training topics and assessment questions corresponding to each of these topics.

Table 1. Training topics and assessment questions

Training Topics	Assessment Questions
Introduction to four-legged robots: History, benefits, challenges, and technologies in construction	1. What are four-legged robots also called?
	2. What are the benefits of four-legged robots in the construction industry?
	3. What are the technologies that four-legged robots use to navigate autonomously on construction sites?
Applications: Monitoring & inspection; Material & equipment delivery	4. How can four-legged robots facilitate construction work?
	5. What technology might four-legged robots use for inspection and monitoring type of applications?
Safety Challenges: Physical risks; Attentional costs; Psychological impact	6. What types of risks do four-legged robots pose to humans?
	7. Which of the following statements is NOT True? A. Four-legged robots' fast or sudden movements may impact human workers' respiratory and vision health B. Four-legged robots cannot distract us when we are working at heights C. The feeling of being watched by four-legged robots can increase the likelihood of an accident; D. Fast-moving legs of four-legged robots can cause physical risks
Countermeasures: Hierarchy of Control	8. What is the most effective strategy to avoid the hazards posed by four-legged robots?
	9. Which of the following statements is an Elimination strategy? A. Replacing a four-legged robot with a drone for collecting data B. Not using any four-legged robots at all C. Using caution tape to keep workers away from the path of four-legged robots D. D. Always wearing safety gloves when working with four-legged robots

The technical development of the virtual site visit includes three main components: the virtual construction site, virtual instructor, and user interfaces (Figure 1). The Unity® game engine was used to create the virtual environment in VR. The virtual construction sites include different construction entities and vehicles based on the scenario's requirements, as well as virtual programs to operate according to their specific role. Virtual construction workers were added to mimic actual construction sites and present possible safety risks associated with interacting with four-legged robots. The virtual instructor, designed using Unity, leads players through the virtual construction site, providing them with on-site learning opportunities about the learning objectives. The instructor's design includes a human body, non-verbal behaviors, narrative audio, lip-syncing, facial expressions, and gesture animations to encourage social exchanges and improve communication between storytellers and audiences (Salem & Earle, 2000). User interfaces include a virtual learning board, a "Back to Instructor" button, and a Mini Map, allowing users to keep track of learning objectives, return to the instructor's location, and identify their own and the instructor's location in the virtual environment. Students interact with these interfaces using a keyboard and mouse. Finally, the virtual site visit was exported as a PC Windows version.

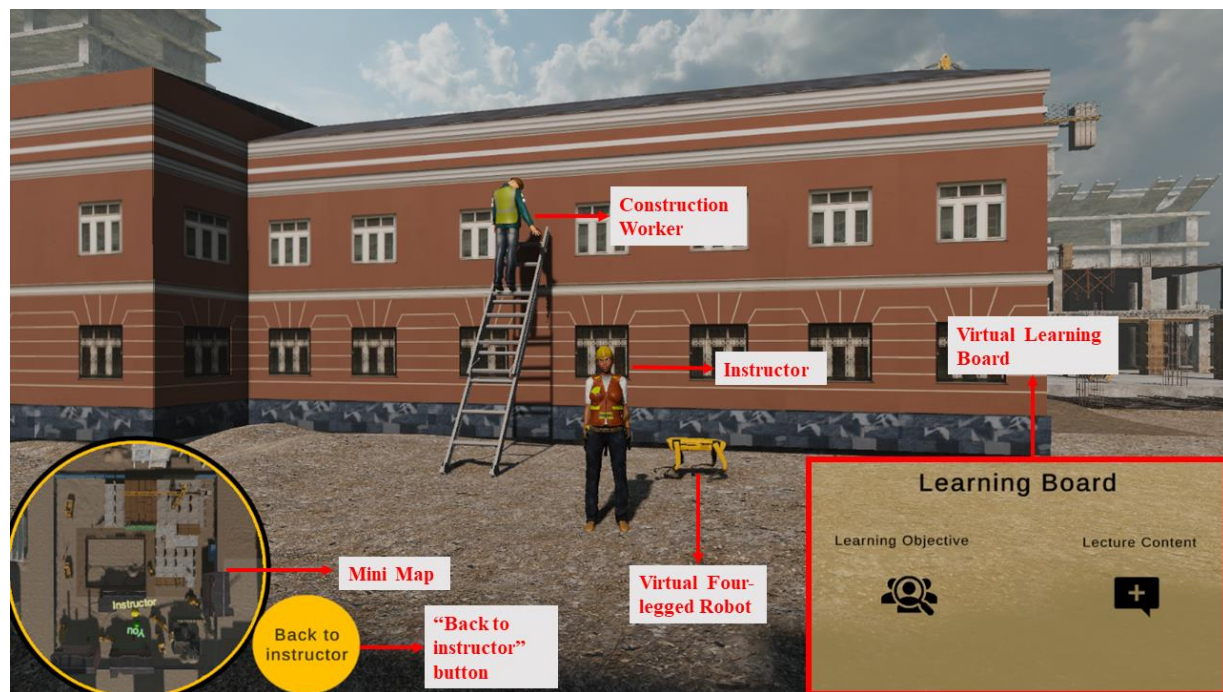


Figure 1. Main User Interface Components of the Virtual Site Visit

Assessment Procedures. Twenty-three students from the College of Design, Construction, and Planning at the University of Florida were recruited to complete the virtual site visit. The experiment was exempted from the UF Institutional Review Board (IRB). These participants have over one year of working experience in the construction industry. The participants first responded to a demographic survey with questions about their gender, educational level, and background, as well as their familiarity with four-legged robots and VR. The study had two primary metrics: learning performance and system usability. A set of nine questions was created to assess users' knowledge level or learning performance during the virtual site visit. These

questions covered the four training topics to evaluate users' learning performance about four-legged robots, their technologies, applications, safety challenges, and countermeasures. These assessment questions were embedded into the virtual site visit. After experiencing the virtual site visit, participants were asked to answer system usability questionnaires (Lewis, 2018). The System Usability Scale (SUS) is a validated 5-point Likert scale designed by Bangor et al. (2009) to measure the perceived usability of a system in a unidimensional manner. The SUS has found widespread application across various disciplines and fields, with several researchers reporting its reliability, validity, and sensitivity to different independent variables. For instance, the SUS has been employed to assess technology acceptance in e-learning contexts (Sun et al., 2022) and examine users' satisfaction and cognitive achievement in virtual environments (Du et al., 2018). In this study, the System Usability Scale (SUS) is utilized to assess the quality of user experience based on its effectiveness (i.e., users' ability to complete tasks using the system), efficiency (i.e., users' resource consumption when performing tasks), and satisfaction (i.e., users' reactions to the system's performance). Moreover, descriptive statistics were used to analyze the demographic survey.

RESULTS AND DISCUSSION

A total of 23 students participated in the virtual site visit study. Table 2 shows their demographic information.

Table 2. Participant demographics

Parameters		Number (Percentage)
Gender	Females	3 (13%)
	Males	20 (87%)
Educational Level	Undergraduates	6 (26%)
	Graduates	17 (74%)
Educational Background	Construction Management	10 (43%)
	Civil Engineering	10 (43%)
	Others (i.e., Landscape, Architecture)	3 (14%)
Familiarity with Four-legged Robots	None	12 (52%)
	Some knowledge of	6 (26%)
	Fair	4 (17%)
	Competent	1 (5%)
Familiarity with Virtual Reality (VR)	None	2 (9%)
	Some Knowledge of	6 (26%)
	Fair	11 (48%)
	Competent	4 (17%)

Learning Performance and System Usability. The objective of the learning performance assessment was to evaluate students' understanding of four-legged robots working on a construction site. After completing the virtual site visit, participants, on average, responded to **78.91% ± 16.0%** of the assessment questions correctly. Students' feedback in an open-ended comment indicated that the virtual site visit improved their understanding of four-legged robots

in construction sites. For instance, one student commented, *“Great training alternative! It covered the applications, challenges, and protective measures that could be used to prevent four-legged robots from creating hazardous situations.”*

A descriptive analysis was performed on System Usability Scale (SUS) reported by the students' post-virtual site visit. Table 3. shows the results of the SUS, indicating an overall usability score of 73.725 out of 100. Based on (Bangor et al., 2009) overall platform usability scoring system, the obtained score is considered “Good.” The results suggest that the usability of this developed system falls between “Excellent” and “OK.” The score (73.725) of the virtual site visit is comparable to other studies exploring the effect of virtual environments in the educational field (Sun et al., 2022). Additionally, some students' feedback acknowledged the potential of such site visits to improve their learning performance and motivation. For example, one student commented, *“I like seeing examples of how robots could help. The tasks don't even have to be complicated, but it would still save money on working time. Getting tools, or maybe delivering water, would be really good. Picking up trash and cleaning the workspace could be really useful for future job sites, in my opinion”* and another one stated that *“The virtual site visit was a relatively straightforward application; not only was I able to learn more about robots in the workplace, but I was also able to understand how fluidly robots could work next to humans in the workplace. The system was straightforward to use and provided a lot of positive thoughts after I had used the system.”* Although the SUS was high and some students reported some positive comments, open-ended comments from other some students indicated a few issues with the platform, including potential usability difficulties (*“Difficulty in hovering over the mouse on the screen because the orientation always changed while I was moving the mouse.”*)

Table 3. System usability scale (SUS) results

Questions	Mean (SD)
Scale: Strongly Disagree (1) – (5) Strongly Agree	
Q1: I think that I would like to use this system frequently	3.74 (0.54)
Q2: I found the system unnecessarily complex.	2.00 (1.00)
Q3: I thought the system was easy to use.	4.04 (0.88)
Q4: I think that I would need the support of a technical person to be able to use this system.	2.04 (1.22)
Q5: I found that the various functions in the system were well integrated.	4.00 (1.00)
Q6: I thought there was too much inconsistency in this system.	1.91 (1.08)
Q7: I would imagine that most people would learn to use this system very quickly	3.96 (0.88)
Q8: I found the system very awkward to use.	2.13 (1.10)
Q9: I felt very confident using the system	4.22 (0.90)
Q10: I needed to learn a lot of things before I could get going with this system.	2.39 (1.50)
Overall Usability Score (Bangor et al., 2009):	73.725

CONCLUSION AND FUTURE WORK

This study proposed the use of the virtual site visit, which integrates immersive storytelling elements and VR technologies, to support construction students in learning about four-legged robots in construction without exposing them to unnecessary risks or incurring significant costs. The virtual site visit enabled users to navigate a robot-dominant construction site and learn about four-legged robots, their applications, safety challenges, and countermeasures for working safely with robots. An experiment was conducted to evaluate 1) students' learning performance after going through the virtual site visit and 2) the platform's usability. Results showed that the platform effectively helped students learn about four-legged robots within the virtual environment. Moreover, the system displayed "Good" acceptability, indicating that it was easy to use and operate, and students could obtain the required information and knowledge by using the platform. However, some of the open-ended comments suggested that the system's usability, specifically the use of the mouse for viewpoint movement, needs further improvement.

To enhance the understanding of the effectiveness of the virtual site visit in educational activities related to construction robots, future studies should consider gathering a larger sample size, including individuals with varying levels of working experience in the construction industry. Furthermore, researchers should collect various qualitative and quantitative measures related to learning, such as learning tests, pre-post motivation surveys, and student interviews, to better evaluate student learning performance. Additionally, performing a more in-depth statistical analysis could provide more insights into the effectiveness of such virtual site visit.

ACKNOWLEDGEMENT

This material is based upon work supported by the National Science Foundation under Grant No. 2141682.

REFERENCES

- Adami, P., Becerik-Gerber, B., Soibelman, L., Doleck, T., Copur-Gencturk, Y., and Lucas, G. (2020). An Immersive Virtual Learning Environment for Worker-Robot Collaboration on Construction Sites. *Proceedings - Winter Simulation Conference*, 2020-December, 2400–2411.
- Afsari, K., Halder, S., Ensafi, M., DeVito, S., and Serdakowski, J. (2021). Fundamentals and Prospects of Four-Legged Robot Application in Construction Progress Monitoring. *EPiC Series in Built Environment*, 2, 274–263.
- Balzan, A., Aparicio, C. C., and Trabucco, D. (2020). Robotics in construction: State-of-art of on-site advanced devices. *International Journal of High-Rise Buildings*, 9(1), 95–104.
- Bangor, A., Kortum, P., and Miller, J. (2009). Determining what individual SUS scores mean: Adding an adjective rating scale. *Journal of Usability Studies*, 4(3), 114–123.
- Bellicoso, C. D., Bjelonic, M., Wellhausen, L., Holtmann, K., Günther, F., Tranzatto, M., Fankhauser, P., and Hutter, M. (2018). Advances in real-world applications for legged robots. *Journal of Field Robotics*, 35(8), 1311–1326.
- Collins, S. (2022, January 26). *How Storytelling Inspires Representation in STEM Communities*. Improving Undergraduate STEM Education Initiative (IUSE); American Chemical Society (ACS).

- Dakhli, Z., and Lafhaj, Z. (2017). Robotic mechanical design for bricklaying automation. *Cogent Engineering*, 4(1).
- Du, J., Shi, Y., Zou, Z., and Zhao, D. (2018). CoVR: Cloud-Based Multiuser Virtual Reality Headset System for Project Communication of Remote Users. *Journal of Construction Engineering and Management*, 144(2), 04017109.
- Eiris, R., and Gheisari, M. (2018). Site visit application in construction education: A descriptive study of students' perspectives. *54th ASC Annual International Conference Proceedings*, 67–73.
- Eiris, R., Jain, A., Gheisari, M., and Wehle, A. (2020). Safety immersive storytelling using narrated 360-degree panoramas: A fall hazard training within the electrical trade context. *Safety Science*, 127.
- Eiris, R., Wen, J., and Gheisari, M. (2021). Influence of Virtual Human Appearance Fidelity within Building Science Storytelling Educational Applications. *Journal of Architectural Engineering*, 27(4), 04021036.
- Eiris, R., Wen, J., and Gheisari, M. (2022). iVisit-Collaborate: Collaborative problem-solving in multiuser 360-degree panoramic site visits. *Computers & Education*, 177, 104365.
- Eiris, R., Wen, J., and Gheisari, M. (2020). iVisit: Digital Interactive Construction Site Visits Using 360-Degree Panoramas and Virtual Humans. *Construction Research Congress 2020: Computer Applications*, 1106–1116.
- Halder, S., Afsari, K., Serdakowski, J., Devito, S., and King, R. (2022). Accuracy Estimation for Autonomous Navigation of a Quadruped Robot in Construction Progress Monitoring. *Computing in Civil Engineering 2021*, 1092–1100.
- Iturralde, K., et al. (2020). *A Cable Driven Parallel Robot with a Modular End Effector for the Installation of Curtain Wall Modules*.
- Jeelani, I., and Gheisari, M. (2021). Safety challenges of UAV integration in construction: Conceptual analysis and future research roadmap. *Safety Science*, 144(July 2020), 105473.
- Kandi, V. R., Castronovo, F., Brittle, P., Mastrolembro Ventura, S., and Nikolic, D. (2020). Assessing the Impact of a Construction Virtual Reality Game on Design Review Skills of Construction Students. *Journal of Architectural Engineering*, 26(4), 04020035.
- Lewis, J. R. (2018). Measuring Perceived Usability: The CSUQ, SUS, and UMUX. *International Journal of Human-Computer Interaction*, 34(12), 1148–1156.
- Madsen, A. J. (2019). The SAM100: Analyzing Labor Productivity. <https://digitalcommons.calpoly.edu/cmisp/243/>.
- Morris, G. A., and Cannady, R. (2019). Proper Use of the HIERARCHY OF CONTROLS. *Professional Safety*, 64(8), 37–40. <https://www.jstor.org/stable/pdf/48689862.pdf>.
- Perry, S., Economou, M., Young, H., Roussou, M., and Pujol, L. (2018). Moving beyond the virtual museum: Engaging visitors emotionally. *Proceedings of the 2017 23rd International Conference on Virtual Systems and Multimedia, VSMM 2017*, 2018-Janua, 1–8.
- Safeea, M., and Neto, P. (2019). Minimum distance calculation using laser scanner and IMUs for safe human-robot interaction. *Robotics and Computer-Integrated Manufacturing*, 58, 33–42.
- Salem, B., and Earle, N. (2000). *Designing a Non-Verbal Language for Expressive Avatars*.
- Shen, Z., Jiang, L., Grosskopf, K., and Berryman, C. (2012). Creating 3D web-based game environment using BIM models for virtual on-site visiting of building HVAC systems. *Construction Research Congress 2012: Construction Challenges in a Flat World, Proceedings of the 2012 Construction Research Congress*, 1212–1221.

- Sun, Y., Albeaino, G., Gheisari, M., and Eiris, R. (2022). Online site visits using virtual collaborative spaces: A plan-reading activity on a digital building site. *Advanced Engineering Informatics*, 53(April), 101667.
- Wen, J., and Gheisari, M. (2021). VR-Electricians: Immersive storytelling for attracting students to the electrical construction industry. *Advanced Engineering Informatics*, 50, 101411.
- Zhang, C., Lu, Y., Xu, R., Ye, X., Shi, Y., and Lu, P. (2017). An Educational Tool based on Virtual Construction Site Visit Game. *Modern Applied Science*, 11(8), 47.