Advancing Construction Robotics Learning through Virtual Reality: A User Experience and Usability Study

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ABSTRACT

Current construction curricula rely on traditional, lecture-based teaching methods, often supplemented by multimedia such as videos, images, and slides. Such passive methods are unable to provide an experiential learning experience, which may translate to reduced skill retention. Given the projected rise of robotics in the construction industry, it is critical to address such technological transformation in the construction curriculum for the next generation of construction professionals. This research aimed to explore VR as a tool to enhance students' knowledge of construction robotics. For this purpose, the study developed a virtual training platform for providing construction engineering students with knowledge on working with simulated robots within the virtual environment of construction sites. To assess the user experience and system usability of the developed immersive learning platform, 40 students underwent an immersive learning experience and provided their feedback through self-assessment questionnaires. Results indicated the effectiveness of the VR approach in delivering a satisfying and user-friendly educational experience in learning construction safety.

INTRODUCTION

The ever-evolving technological landscape is undergoing a profound transformation, with robotics technology at the forefront of reshaping numerous industries (Sweet 2018). Rapid advancements in robotics, engendered by artificial intelligence and sensor technologies, are paving the way for the future where collaboration between humans and robots becomes the norm. Such collaboration will be more evident in the construction sector, which has long grappled with issues such as labor shortages, limited productivity, and workplace safety concerns. With the advent of robotic innovations, the construction industry is on the cusp of significant transformations. Studies have indicated that 81% of the world's construction companies are planning to incorporate robots into their operations over the next two decades (ABB Construction Industry Survey 2021). As robots assert their presence in the construction industry, the skill set required for future professionals should evolve in tandem with the technological advancements. Within such an evolving technological landscape, it is imperative for construction engineering and management (CEM) education to embrace a curriculum that imparts foundational knowledge about technological advancements.

In the conventional CEM education practices, there is a prevalent reliance on passive instructional methods, notably lecture-based sessions. However, such traditional pedagogical methods fall short in effectively teaching emerging technologies in construction (Scott 2016). Firstly, such methos lack the interactivity required to engage the learners with complex technological concepts. Slide-based lecture sessions often fail to convey the hands-on experience necessary to understand the nuances of emerging technologies, leaving students with a superficial grasp of the necessary concepts (Scott 2016). Secondly, passive learning tends to present information in a linear and structured manner. Passive learning often lacks the complexity and real-world ambiguity that students might encounter when working with cutting-edge tools and methodologies. Passive slides do not encourage students to think critically or analyze problems, because they typically offer a predetermined sequence of information without room for exploration. In contrast, immersive technologies offer a promising alternative (Le et al. 2015). By creating virtual environments that mimic real construction scenarios, learners can actively engage with emerging technologies, gaining hands-on experience in a risk-free setting. This hands-on approach fosters a deeper understanding of the subject matter, encourages exploration, and allows learners to make mistakes and learn for them such as 'learning by doing'. In this regard, immersive learning holds the potential to revolutionize education in construction by offering an interactive, experiential, and effective way to teach emerging technologies (Le et al. 2015).

While immersive learning environments hold immense potential in revolutionizing the construction industry, it is critical to underscore the significance of user experience and usability in their design and implementation tools (Orfanou et al. 2015; Santoso et al. 2016). User experience plays a vital role in the effectiveness of pedagogical. When users find joy and value in the learning process, they are more likely to remain motivated, actively participate, and retain knowledge over the long term. On the other hand, usability ensures that the educational tools are accessible and user-friendly, allowing learners from diverse technical backgrounds to benefit fully. Ensuring that pedagogical tools are both satisfying and usable broadens their reach, making them cost effective and inclusive for learners. Towards this end, the study aims to develop and investigate immersive VR-based learning modules specifically tailored for understanding the learner satisfaction and usability aspects related to construction robotics education. This research endeavors to shed light on the extent to which VR-based learning can enhance both user experience and usability in the field of construction robotics. Ultimately, this research will contribute valuable insights that can inform the development and implementation of VR-based educational tools, optimizing their impact and accessibility for users in the construction industry and beyond.

GROWTH OF ROBOTICS TECHNOLOGY IN CONSTRUCTION SECTOR

In recent years, the construction industry has experienced a significant transformation with the introduction of robotics technology. Such incumbent shift is a response to the long withstanding challenges that have plagued the construction industry, including stagnant low productivity, labor shortages, and safety issues costs (Karimi et al. 2018). The initial foray into robotics in the construction industry encompasses automated solution designed for physically intensive and repetitive task such as flexible manufacturing system-integrated bricklayer (Altobelli et al. 1993) and experimental masonry system (Rihani and Bernold 1994). However, the construction environment, marked by its dynamic, unstructured nature and the constant presence of machinery and human workers, posed substantial obstacles to the widespread adoption of highly autonomous robots. A pivotal challenge for automated technologies within the construction industry lies in adapting to the swiftly changing work environments. Creating dedicated space for the safe operation of fully automated systems has proven to be a logistical nightmare. In response, the construction industry has recognized the value of human expertise and the imperative of prioritizing Human-Robot Collaboration (HRC) over complete automation. Recent technological advancements have paved the way for an era in which robots collaborate seamlessly with human counterparts, evident by the emergence of collaborative robots, often referred to as cobots workers (Afsari et al. 2018). Collaborative robots are notable for their ability to merge human adaptability with the precision, speed, and endurance inherent to robotic systems. This combination of capabilities facilitates enhanced productivity and opens new possibilities. Crucially, collaborative robots are not designed to replace human workers but to serve as a companion during construction operations. In this vein, the future of construction sector hinges on the harmonious coexistence of workers and robotic expertise. As robots become more prevalent, CEM professionals need to safely engage with these systems. Workers must trust new technologies, understand processes, and adapt to technology-driven settings. The complexities of new robotic systems also demand that CEM professionals establish connections with them through new interfaces, underscoring the necessity for a deeper understanding of human-robot interaction mechanisms. Consequently, it is imperative to incorporate knowledge and skills related to human-robot interaction into CEM education to address the uncertainties surrounding interactions with robotic systems.

IMMERSIVE LEARNING FOR CONSTRUCTION ROBOTICS

In CEM education, the conventional approach to conveying essential knowledge about the construction sector has predominantly involved passive pedagogical methods (Scott 2016). These methods typically encompass lecture-based sessions complemented by multimedia resources such as images, videos, slide presentations, or pamphlets. However, when applied to the intricate and potentially hazardous context of construction workplaces, these conventional techniques often prove inadequate in effectively imparting and retaining essential information for learners (Scott 2016). Recognizing such limitations, various emerging technologies are poised to reshape CEM education, which includes mobile applications, massive open online courses, immersive technologies are among the innovative tools that have garnered attention to offer diverse ways in enhancing learning experiences. However, among these technologies, VR stands out as having significant potential (Le et al. 2015). VR environments have the unique ability to immerse learners in realistic and interactive scenarios related to construction processes and robotics. Such immersive learning enables students to actively participate in hands-on experiences without the constraints and safety concerns of real construction sites. This simulated approach bridges the gap between theoretical understanding and practical application, ensuring that learners not only grasp the concepts but also develop the skills and confidence needed to excel in the construction industry's dynamic and technologically advanced landscape. However, the potential of VR in CEM education extends beyond the mere delivery of content and encompasses the critical aspects of “user experience” and “usability” within these immersive environments. User experience plays a vital role in the effectiveness of pedagogical tools (Santoso et al. 2016). When users find joy and value in the learning process, they are more likely to remain motivated, actively participate, and retain knowledge over the long term. Usability, on the other hand, refers to the ease with which learners can navigate and interact within the VR-based environment (Orfanou et al. 2015). Usability ensures that the educational tools are accessible and user-friendly, allowing students from diverse technical backgrounds to fully benefit from the experience. Ensuring that VR-based learning environments are both satisfying and usable is essential to maximize their impact and reach, making them cost-effective and inclusive for learners. Given the transformative potential of VR in CEM education, it becomes imperative to assess the user experience and usability of these immersive environments. Such assessment ensures the creation of immersive, engaging, and user-friendly VR educational resources tailored to the unique demands of CEM.

IMMERSIVE TECHNOLOGIES-BASED LEARNING OF CONSTRUCTION ROBOTIC SAFETY AND ITS IMPACTS ON STUDENTS LEARNING

The primary objective of this research is to investigate the effectiveness of VR as a pedagogical tool in learner satisfaction and usability in the context of construction robotics education. In this regard, a specialized VR-based learning module was developed to improve learners' understanding of construction robotic safety. The study follows a structured approach to assess the impact of immersive learning on user experience and usability. It consists of two key phases, as illustrated in Figure 1.

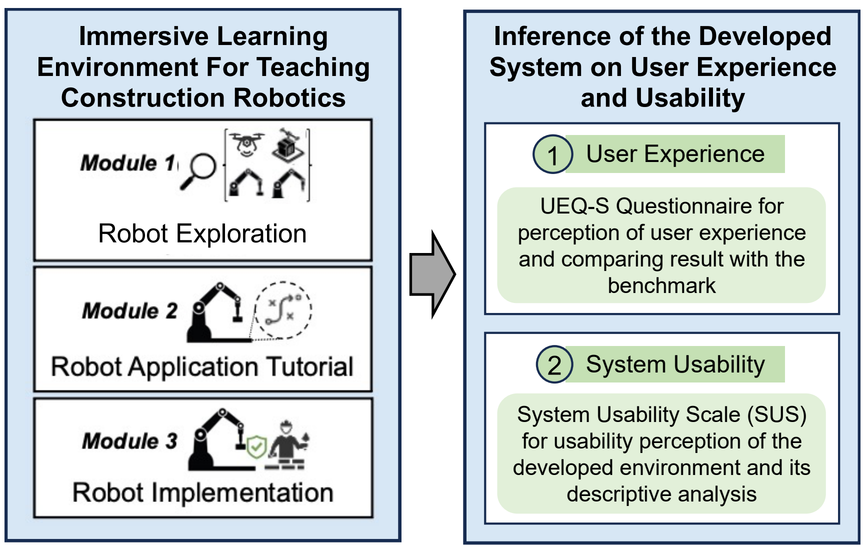

Figure 1. Overview of the proposed steps for investigating immersive learning environment for teaching construction robotics on user experience and usability.

Firstly, a virtual learning environment was developed to provide comprehensive insights into construction robotics. Secondly, an analysis was conducted to evaluate the impact of the developed immersive learning in user experience and usability. To conduct a comparative analysis between the VR-based approach and conventional methods, a cohort of 40 students from diverse educational backgrounds was recruited for this study. All the recruited students took turns in experiencing the developed learning environment, respectively. Then, a self-assessment technique was leveraged to measure the learner satisfaction and system usability across the two learning scenarios. The user experience of the developed immersive learning environment was evaluated by using a modified version of the User Experience Questionnaire (UEQ-S) (Schrepp et al. 2017). Likewise, the usability of the simulated learning environment was evaluated using the context specific System Usability Scale (SUS) (Brooke 1996). Prior to commencing the study, all participants provided informed consent and were briefed on the confidentiality of data and their rights as participants. Health-related information was also collected, with all participants reporting normal or corrected vision, and no indications of oculomotor or neurological issues.

Development of Immersive Learning Environment for Teaching Construction Robotics

The proposed learning environment featured a high-fidelity simulation of an actual construction jobsite integrated with instructional modules to characterize different aspects of working with construction robots. For this purpose, a construction jobsite was modeled in Autodesk Revit and imported into the Unity game engine. Also, different elements of the immersive environment were created as Game Objects featuring collider and Rigidbody components to show realistic physical properties. The creation of various components within the scene was done using., Blender) as well as game engine built-in functions. The game engine also provided the capability to enhance the scene with realistic textures, sounds, and lighting effects. The proposed learning environment consists of three modules, as shown in Figure 2.

Module 1- Robot Exploration: This module educates students about different construction robots (e.g., concrete printing robots, bricklaying robots, drones, etc.). In this module, students could select the preferred type of robot through an interactive menu to access general information about each robot. Each specific part of the robot (e.g., robotic arm, control panel, actuators) was integrated with the required specifications in the form of a text box accessed by selecting each part. The interactive menu allowed inputs from the students to trigger scripts to manipulate different Game Objects. Students were able to safely inspect the robots from different angles and preferred distances to enhance their understanding of the functionality, workspace, and operational requirements of each robot.

Module 2- Robot Application Tutorial: This module offered comprehensive instructions on interacting with various robots to mitigate construction risks effectively. In this module, students observe a virtual expert planning robot placement based on rules and criteria. This virtual robotic expert was a 3D humanoid model, capable of performing kinematic movements and verbal expressions about the process that is being performed. To develop the humanoid, the required body movements will be recorded using a motion capture system based on our previous work (Ojha et al. 2022). Firstly, the virtual expert demonstrated how to choose the best zone to place the robot in terms of the project cost and duration. Then, the module challenged students to select optimal robot placement zones while considering probable conflicts, risks, and best possible outcome.

Module 3– Robotic Implementation: This module focuses on task-oriented robotic control, allowing students to operate and control robots to perform specific construction tasks. In this module, students were guided through the fundamentals of controlling each type of robot and will be asked to complete a specific task through several iterations. In addition, students were guided with instructions regarding safety mechanisms and safety precautions for working with robots based on regulations and policies of the Occupational Safety and Health Administration (OSHA) and the International Organization for Standardization (ISO).

Inferences on User Experience and Usability

The significance of user experience is paramount for the acceptance of immersive learning environment. In this study, User Experience Questionnaire (UEQ-S) is used for assessment of user experience. UEQ-S measures two dimensions of the user experience. The UEQ-S contains eight items rated through the 7-stage Likert scale, allows a quick assessment of user experience, and measures two dimensions of user experience, as shown in Table 1.

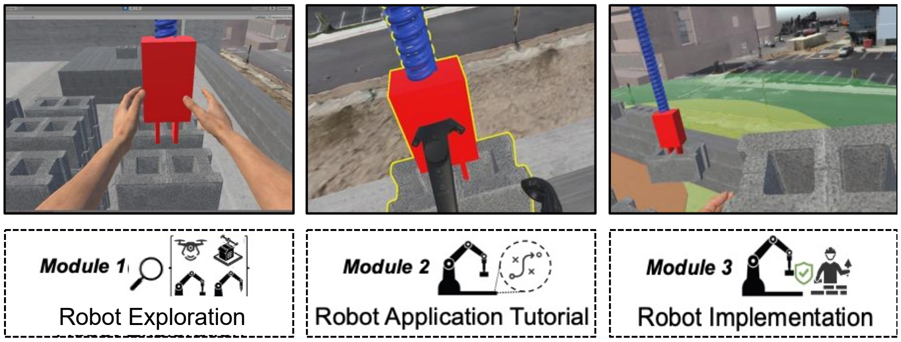

Figure 2. Modules of the Developed Immersive Learning Environment

Table 1. UEQ-S Scale (Schrepp et al. 2017)

	Negatives	Positive
Pragmatic Quality	Obstructive	Supportive
	Complicated	Easy
	Inefficient	Efficient
	Confusing	Clear
Hedonic Quality	Boring	Exciting
	Not Interesting	Interesting
	Conventional	Inventive
	Usual	Leading Edge

These two dimensions of user experience include pragmatic quality and hedonic quality. Pragmatic quality assesses the system's effectiveness and efficiency in fulfilling user objectives, while hedonic quality gauges the user's emotional responses, such as pleasure or enjoyment, during interaction with the system. Responses are recorded using a 7-point Likert scale, where -3 represents a complete agreement of the negatively connoted term, 0 indicates a neutral stance, and +3 signifies full agreement with the positively connoted term. The UEQ-S contains a benchmark that helps to decide how good or poor a system is. In this regard, the benchmark used to compare the user experience of the system was adopted from (Hinderks et al. 2018). The UEQ-S benchmark classifies user experience quality into several categories. For a product to be rated as "Excellent," it must have a pragmatic quality score above 1.73, a hedonic quality score exceeding 1.55, and an overall quality score greater than 1.58. A product is considered "Good" if it falls within certain ranges: pragmatic quality between 1.55 and 1.73, hedonic Quality between 1.25 and 1.55, and overall quality from 1.4 to 1.58. In the "Above Average" category, pragmatic quality ranges from 1.15 to 1.54, hedonic quality from 0.88 to 1.24, and overall quality from 1.02 to 1.39. Conversely, products in the "Below Average" category have pragmatic quality scores between 0.73 and 1.14, hedonic Quality from 0.57 to 0.87, and overall quality from 0.68 to 1.01. Lastly, products considered "Bad" is characterized by pragmatic quality scores below 0.73, hedonic quality under 0.57, and an overall quality less than 0.68. Likewise, to assess the usability of the system, the authors implemented a modified version of the System Usability Scale (SUS) (Brooke 1996). These statements were rated on a 5-point Likert scale, with 1 indicating complete disagreement and 5 indicating complete agreement. To validate the consistency of the usability evaluation, the authors performed a reliability analysis on the adapted SUS using the Cronbach's alpha test. The analysis resulted in a Cronbach's alpha of 0.76, indicating a good level of internal consistency.

RESULTS AND DISCUSSION

The summary of the average user experience for the developed system compared with the benchmark is shown in Figure 3.

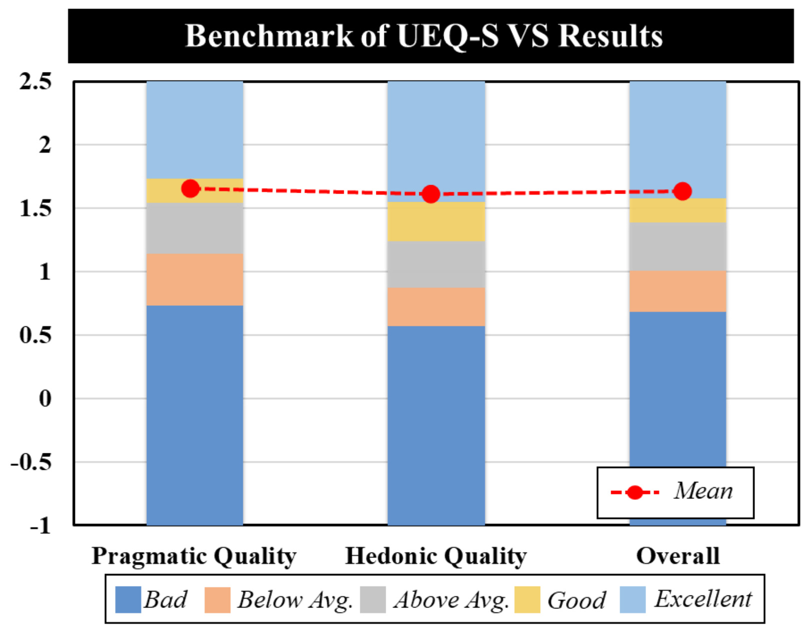

Figure 3. Results for User Experience Analysis Compared with the Benchmark

Results indicated that the average pragmatic quality for developed system was 1.62 and the average hedonic quality for the developed immersive learning environment was 1.58. Compared with benchmark, the pragmatic quality falls under good category which suggests that the immersive learning environment has good level of interaction as is very helpful for instilling students with the required knowledge of construction robotics. Similarly, the hedonic aspect falls under the excellent category which suggests that the students experience a lot of pleasure and joy while learning in an immersive learning environment. Figure 3 also illustrates that the average overall quality of the immersive learning environment was 1.6. As compared with the benchmark, the overall quality of the developed immersive learning environment falls on the excellent category. The analysis of student responses to the usability statements provides valuable insights into their perception of the developed immersive-learning environment's usability. Table 2 summarizes the results of the quantitative analysis of the learners' view on usability of the developed learning environment.

Table 2. Developed Immersive Learning Platform Usability Results

System Usability Statements	Mean	SD
1. I think that I would like to use this developed immersive-learning environment frequently.	3.25	1.05
2. I found the immersive environment unnecessarily complex.	1.40	0.94
3. I thought the learning environment was easy to use.	4.42	0.68
4. I think that I would need the support of a technical person to be able to use the immersive learning system.	1.82	0.99
5. I found the various functions in the develop learning system well-integrated.	3.97	0.87
6. I thought there was too much inconsistency in the immersive learning environment.	2.2	0.96
7. I would imagine that most people would learn to use the developed learning system very quickly.	4.28	0.78
8. I found the learning environment very cumbersome to use.	2.28	1.21
9. I felt very confident in using the developed learning system.	4.12	0.79
10. I needed to learn a lot of things before I could get going with the learning environment.	1.85	1.03

Students generally demonstrated a high level of agreement with several usability statements, indicating their positive perception of the system's usability. For instance, statement #3, which assessed whether students found the learning environment easy to use, received a notably high mean score of 4.42±0.68. This indicates that many students found the system user-friendly and intuitive. Statement #5, focusing on the integration of various functions within the system, also received a positive response, with a mean score of 3.97±0.87. Students generally believed that the system was well-structured and offered a cohesive learning experience. Likewise, statement #7 regarding the ease of learning of how to use the system, had a mean score of 4.28±0.78, reflecting the students' perception that system was quick to grasp and navigate. Moreover, statement #9, which assessed students' confidence in using the system, received a positive response, with a mean score of 4.12±0.79, which suggests that the students felt comfortable and proficient in utilizing the immersive learning environment. On the other hand, statement #1, which inquired about the likelihood of students frequently using the system, resulted in a neutral mean score of 3.25±1.05. This suggests that students neither strongly agreed nor disagreed regarding the frequency of system use, indicating a degree of uncertainty. However, students disagreed with statement #2, which assessed the perceived complexity of the immersive environment, with a mean score of 1.40±0.94. This indicates that students generally found the system straightforward and not unnecessarily complex. Statement #4, which addressed the need for technical support, garnered disagreement from students, with a mean score of 1.82±0.99. This implies that students felt self-sufficient in using the system and did not perceive a significant requirement for technical assistance. While statement #6 indicated slight disagreement regarding inconsistency in the system (2.20±0.96), statement #8 suggested that students found the system somewhat cumbersome but not excessively so, with a mean score of 2.28±1.21. Finally, statement #10, which questioned the need for extensive learning before using the system, resulted in disagreement from students, with a mean score of 1.85±1.03.

CONCLUSION

This study aims to investigate the effectiveness of VR as a pedagogical tool in learner satisfaction and usability in the context of construction robotics education. For this purpose, the authors developed a virtual learning environment was developed to provide comprehensive insights into construction robotics. Simultaneously, an analysis was conducted to evaluate the impact of the developed immersive learning in user experience and usability. The findings of the study indicated that the developed immersive learning environment had a good level of interaction and was very helpful for instilling students with the required knowledge of construction robotics. Likewise, the students experience a lot of pleasure and joy while learning in an immersive learning environment. Additionally, the quantitative analysis of the student responses indicates a favorable perception of the usability of developed immersive-learning environment. Results indicated that the system was perceived as user-friendly, intuitive, and providing a cohesive learning experience. Further, the students indicated confidence in handling the system, coupled with an appreciation for its straightforwardness and ease of navigation. While the results indicated some ambiguity regarding usage frequency and minor issues with consistency and cumbersomeness, the environment was broadly seen as uncomplicated and accessible without the need for extensive learning or technical support. The study underscores the effectiveness of virtual reality in enhancing construction education, aiming to prepare future construction experts with vital skills for safe HRC.

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REFERENCES

ABB Construction Industry Survey. 2021.

Afsari, K., S. Gupta, M. Afkhamiaghda, and Z. Lu. 2018. “Applications of Collaborative Industrial Robots in Building Construction.” *54th ASC Annual International Conference*, 472–479.

Altobelli, F., H. F. Taylor, and L. E. Bernold. 1993. “Prototype Robotic Masonry System.” *J Aerosp Eng*, 6 (1): 19–33.

Brooke, J. 1996. “SUS: a “quick and dirty’usability.” *Usability evaluation in industry*, 189. CRC press.

Hinderks, A., M. Schrepp, and J. Thomaschewski. 2018. “A benchmark for the short version of the user experience questionnaire.” *WEBIST 2018 - Proceedings of the 14th International Conference on Web Information Systems and Technologies*, 373–377. SciTePress.

Karimi, H., T. R. B. Taylor, G. B. Dadi, P. M. Goodrum, and C. Srinivasan. 2018. "Impact of Skilled Labor Availability on Construction Project Cost Performance." *J Constr Eng Manag*, 144 (7): 04018057. American Society of Civil Engineers (ASCE).
Le, Q. T., A. Pedro, and C. S. Park. 2015. "A Social Virtual Reality Based Construction Safety Education System for Experiential Learning." *Journal of Intelligent and Robotic Systems: Theory and Applications*, 79 (3–4): 487–506. Kluwer Academic Publishers.
Ojha, A., M. Habibnezhad, and H. Jebelli. 2022. "Feasibility of Embodied Virtual Agents for Augmenting Students' Knowledge of Robotic Safety in Construction." *Construction Research Congress 2022: Health and Safety, Workforce, and Education - Selected Papers from Construction Research Congress 2022*, 4-D: 70–80. American Society of Civil Engineers.
Orfanou, K., N. Tselios, and C. Katsanos. 2015. "Perceived usability evaluation of learning management systems: Empirical evaluation of the System Usability Scale." *The International Review of Research in Open and Distributed Learning*, 16 (2): 227–246. Athabasca University.
Rihani, R. A., and L. E. Bernold. 1994. "Computer Integration for Robotic Masonry." *Computer-Aided Civil and Infrastructure Engineering*, 9 (1): 61–67.
Santoso, H. B., M. Schrepp, R. Y. K. Isal, A. Y. Utomo, and B. Priyogi. 2016. "Measuring User Experience of the Student-Centered e-Learning Environment." *Journal of Educators Online*, 13 (1): 58–79. Journal of Educators Online. 500 University Drive, Dothan, AL 36303. Web site: http://www.thejeo.com.
Schrepp, M., J. Thomaschewski, and A. Hinderks. 2017. "Design and Evaluation of a Short Version of the User Experience Questionnaire (UEQ-S)." *International Journal of Interactive Multimedia and Artificial Intelligence*, 4 (Regular Issue): 103–108. IMAI Software - International Journal of Interactive Multimedia and Artificial Intelligence.
Scott, L. M. 2016. "Theory and research in construction education: the case for pragmatism." *Construction Management and Economics*, 34: 552–560.
Sweet, R. 2018. "The contractor who invented a construction robot." *Construction Research and Innovation*, 9: 9–12.