

iVisit: Digital Interactive Construction Site Visits Using 360-Degree Panoramas and Virtual Humans

Ricardo Eiris¹; Jing Wen²; and Masoud Gheisari³

¹Ph.D. Candidate, Human-Centered Technology in Construction (HCTC) Research Group, Rinker School of Construction Management, Univ. of Florida, Gainesville, FL, USA. E-mail: reiris@ufl.edu

²Ph.D. Student, Human-Centered Technology in Construction (HCTC) Research Group, Rinker School of Construction Management, Univ. of Florida, Gainesville, FL, USA. E-mail: wen.jing@ufl.edu

³Assistant Professor, Human-Centered Technology in Construction (HCTC) Research Group, Rinker School of Construction Management, Univ. of Florida, Gainesville, FL, USA. E-mail: masoud@ufl.edu

ABSTRACT

Site visits or field trips are an integral part of construction management education, providing students with experiential learning of jobsite conditions. However, these types of real-world opportunities are difficult to obtain within the current educational framework based on classroom instruction. To expose students to jobsite spatiotemporal contexts (spatial, temporal, or social situations), field trips must be organized at locations that are often inaccessible, dangerous, or expensive to reach. To address field trip barriers, this research proposes the use of iVisit—a proof-of-concept platform for guided interactive site visits that leverages 360-degree panoramas and virtual humans. In this paper, the technical requirements for the creation of digital site visit experiences and resulting educational platform are explained in detail. Additionally, a pilot study was conducted to assess the iVisit platform in terms of usability, presence, and student knowledge gains. A masonry materials' site visit learning experience was designed and tested with 10 participants at introductory level construction courses. It was found that students perceived the iVisit guided tour as easy to use (SUS Usability Score – Mean = 86%; STD = 8.8%) and highly realistic (SUS Presence Score – Mean = 68.4%; STD = 14.4%). However, students answer approximately one-third of the presented knowledge questions correctly (Student Knowledge Score – Mean = 31.7%; STD = 25%). These outcomes in student knowledge gains were linked to low image quality in the 360-degree captures and augmented pictures within the digital site. Supporting feedback provided by the study participants suggested that future improvements to iVisit require higher image quality and some refinements to its user-interfaces to increase presence and knowledge gains.

INTRODUCTION

Educational site visits or field trips have become an essential part of construction programs. Instructors utilize visits to provide students with hands-on experiences of the complex and dynamic conditions existing in the jobsite. Field trips also enable students to interact with experts and professionals, offering their expert perspective regarding real-world challenges within construction settings. The direct exposure to construction sites has been found to facilitate the visualization of abstract information (Blinn et al. 2015), increase awareness of real-world professional practices (Eiris and Gheisari 2018-a), and actively motivate and engage student learning (Forsythe 2009). Moreover, site visits have been validated as an effective method to

support classroom teaching by reinforcing concepts taught in traditional instruction settings (Kajewski 1999). Students placed in site visit learning situations experience spatial, temporal, or social contextual information that is unique to each project (e.g., a certain space, changes with time, and interactions with peers). These set of the site-centric physical and social situations conforms the spatiotemporal context of the jobsite (Mutis 2018). In the construction domain, spatiotemporal contexts are distinct for every jobsite due to inherently transient factors such as location, materials, machinery, and personnel. These factors introduce wide variability and changes in project conditions as work progresses. Consequently, spatiotemporal contextual constraints present educational challenges for instructors to successfully integrate relevant site visits that coincide with curricular needs.

Site visits possess additional implementation challenges that are not directly associated with the educational spatiotemporal context. Often, institutional barriers exist in the form of large class sizes, time conflicts, and resource limitations (Eiris and Gheisari 2017-a). Coordinating field trips that accommodate these institutional barriers requires extensive support from university faculty and staff, in addition to assistance from external entities (e.g., private companies, state agencies). Other barriers are associated to the availability of jobsites that are within reasonable commuting distance from university locations. Long commutes introduce difficulties for on-campus students to get jobsite hands-on experience and eliminate any possibility of exposure for online students that do not physically attend construction programs. Furthermore, students that make it to the jobsite have limited access to the spatiotemporal contexts. Busy jobsites and work schedules, liability and safety concerns, or unexperienced tour guides limit student access to certain areas or aspects of the project, hindering the quality of learning provided from the visits (Kajewski 1999, Eiris and Gheisari 2017-a).

Because of the nature of site visits – inaccessible, dangerous, or expensive to reach, digital or virtual environments has been explored as an alternative for educational site visits. The use of virtual environments for construction education has been found beneficial due to their ability to illustrate the spatiotemporal context of the real-world construction site while providing safe, repeatable, and location-independent experiences to students (Goedert and Rokooei 2016). Commonly used virtual environments for construction education leverage 3D modelled construction sites using technologies such as Building Information Modeling (BIM). However, these modeled reproductions of complex real-world conditions can be time-consuming to produce, computationally demanding in terms of hardware, and generate virtual environments that significantly differ from the real-world location counterparts (Wang and Dunston 2007).

This proof-of-concept research project presents one emerging approach to existing 3D modeled educational virtual environments – 360-degree panoramas. The use of 360-degree interactive digital environments powered by virtual humans provides opportunities for instructors to incorporate real-world site visits into classroom teaching. Within digital interactive construction sites – *iVisit* – students can navigate the data-rich spatiotemporal context of a real construction project and observe various challenges in the 360-degree captured learning occasions while guided by replicas of construction professionals (virtual humans). This paper describes the technical development of the *iVisit* educational platform using 360-degree panoramas and virtual humans. The generation of 360-degree panoramic environments, the techniques for introducing virtual humans as digital tour guides, and the resulting educational platform are explained in detail. Additionally, the ability to deliver site visit experiences using the *iVisit* platform was assessed through a pilot study aimed towards a module in construction masonry materials.

BACKGROUND

Digital game-based learning utilizes virtual environments as a method to deliver educational content to the user. Virtual environments are defined as digitally created spaces where users can interact with data in different forms such as models, text, or audio (Rosenman et al. 2006). Learning affordances such as spatial visualization, cognitive exploration, and reflexive feedback have been identified as part of the instructional and pedagogical outcomes of digital game-based learning. Virtual environments in the construction management domain have been developed to produce interactive experiences, enabling students to explore, visualize, and examine complex information in the spatiotemporal context of jobsites. These digital spaces have been found to enable hands-on discovery and creativity, environment visualization, and information transfer, retention, and learning (Castronovo et al. 2017).

A significant amount of research has been done on learning within digital construction sites. These 3D modeled environments have been used to deliver active exploration of real-world site conditions, often assisted by information-rich virtual humans. Virtual humans are computer-generated replication of humans that offer an interaction medium for information exchange (Eiris and Gheisari 2017-b). For example, Anderson and Dossick (2014) employed a game framework to explore model issues in Building Information Models (BIM). Virtual humans allowed students to converse in the 3D virtual world for location navigation and visualization. More recently, Eiris and Gheisari (2018-b) used conversational virtual humans to allow the students to practice communication skills in a simulated construction site. A pilot study was presented where a lifting operation took place in an inaccessible roof of a high-rise construction site.

Other approaches in virtual educational environments are investigating the use of 360-degree panoramas to simulate construction sites. This reality capturing technique delivers a surrounding view captured the real-world environment with a high sense of presence (Bourke 2014). In contrast to traditional 3D modeled virtual environments, 360-degree panoramas offer fast digital jobsite generation, easy to produce simulations, and high levels of realism due to the inherent photography techniques used in this technology. Consequently, 360-degree panoramas have been increasingly used to create digital jobsites for educational purposes. For instance, Pham et al. (2018) developed a learning platform for improving safety education field trips using 360-degree panoramas. The created platform allowed students to look at a digital site visit to recognize hazards using 360-degree panoramas. The platform enabled the assessment of safety knowledge learned from the site exploration using gamified testing mechanisms. In another example, Kim et al. (2019) utilized 360-degree panoramas for student experiential learning in a virtual site visit, specifically illustrating the construction progress of a foundation wall over the span of four months. The researchers found that student had positive attitudes towards the experience and reported high levels of student understanding for construction sequencing in the virtual environment.

RESEARCH MOTIVATION AND POINT OF DEPARTURE

A plethora of challenges, including inaccessible spatiotemporal contexts, institutional limitations, and student safety challenges, have limited the implementation of real-world site visits in the current construction curricula. In response, research efforts have utilized virtual environments to provide students with simulations of real-world construction sites while maintaining a low-cost, safe, repeatable, and location-independent experiences. Growing evidence supports that virtual environments enable student learning analogous to real-world

settings. However, effective learning within virtual environments is limited by the level of realism embedded in the digital settings. Traditionally, 3D modeled virtual environments are leveraged to deliver digital learning experiences. Literature suggests that the level of detail used in 3D modeled virtual environments needs to be improved to enhance the feeling of physical presence (Taylor et al. 2018). Achieving close-to-reality 3D modeled virtual environments is often impossible. These types of virtual environments require large amounts of resources necessary to model real-world situations and necessitate high computational cost for rendering. More importantly, due to the realism constraints of simulated physical environments, students often do not perform with the same proficiency as they do in real-world (Wang and Duston 2007). Therefore, academicians have investigated the use of 360-degree panoramas as an alternative to delivering student learning in realistic digital environments. Nevertheless, the use of interactive construction sites employing 360-degree panoramas powered by virtual humans remains unexplored. The point of departure of this study is to utilize *iVisit* as a proof-of-concept to enable students a virtual human guided tour of a 360-degree panoramic construction site visit for experiential learning. By utilizing the unique advantages of *iVisit* – augmented real-world 360-degree contexts and virtual human-based information delivery – this study aims to supplement current site visit activities when these are available within the construction curriculum or to offer an alternative when these are not available to students.

IVISIT: DIGITAL INTERACTIVE SITE VISIT PLATFORM DEVELOPMENT

The proof-of-concept platform developed in this study aims to provide students an interactive guided site visit experience. The creation of *iVisit* digital interactive site visits required the development of two distinct platform components: (1) 360-degree panoramas and (2) virtual humans. Figure 1 illustrates the combined platform components, resulting in the *iVisit* (3) digital interactive site. The platform employs (1) 360-degree panoramas augmented with layers of information to visualize the complex spatiotemporal context of construction jobsites. When using this platform, students can experience the jobsite environment to gain spatiotemporal information through observation and interaction. Augmented contents in the view can be activated by the student to provide them more detailed knowledge about certain spatiotemporal contexts onsite. Analogous to a real-world field trip, students can visualize various locations within a jobsite by switching scenes. In *iVisit*, (2) virtual humans are used to further connect the spatiotemporal contents with conceptual information displayed in the augmented 360-degree panoramas. These virtual humans represent construction professionals involved in various aspects of a given project (such as project engineer, safety inspector, or superintendent). Voice recording narrations and non-verbal cues (e.g., pointing, waving, or walking) are utilized by the virtual human to guide the student during the site visit. Finally, the resulting (3) digital interactive site focuses on providing students means of interaction with the spatiotemporal context using a head-mounted display. A virtual clipboard drives interactive menu that helps students to control the visit progress, tracking educational learning objectives. The technical development details of each *iVisit* platform element are described below in this section.

- (1) *360-Degree Panoramas*: The creation of the 360-degree panoramic environment requires to follow a three-step process: capture, authoring, and visualization. The first step entails the capturing of data from real-world jobsite locations. Often, 360-degree panoramic cameras (e.g., Insta360 One®, Samsung GearVR®, or Ricoh Theta V®) are used to collect this type of photographic data. Subsequently, in the second step, the capture data must be transformed into an equirectangular projection in the authoring processes.

Computer software provided by the different camera manufacturers automate this task. Finally, the visualization step entails remapping the 360-degree images into spherical coordinates to generate an explorable panoramic environment. Game engines can be used to create and render such panoramic environment. This study utilizes the Unity® game engine to develop the *iVisit* platform.

- (2) *Virtual Human*: The generation of a virtual human includes the creation of a 3D character model, animations that convey non-verbal information, and voice recording narratives. A 3D character is created to model the human physical body using a computer-generated geometrical representation. The software Adobe Fuse CC® was used to assemble and modify character components, including animations. Animations are generated to convey body language and gestures, mimicking communicational aspects that real humans produce during information exchanges (e.g., pointing at objects, postures during a speech, or maintaining eye contact). Finally, voice recordings are produced to accompany the virtual human. These audio files are constructed to specifically fit the guided site visit and complement the visual demonstrations in the augmented 360-degree panoramas. The virtual human voice was generated using the IBM Watson® text-to-speech tools, which synthesizes natural-sounding human articulations.
- (3) *Digital Interactive Site*: The *iVisit* platform integrates the created 360-degree panoramas and the virtual human using the Unity® game engine. Within the game engine, three components are introduced into the platform to drive student interactions: (1) augmented contents, (2) virtual human kinematics, and (3) user interfaces. First, the (1) augmented contents such as data, objects, or sounds are superimposed into the virtual environment. This environment augmentation process provides a data enrichment of the site to offer students details about the spatiotemporal context of the jobsite. Hotspots (glowing spheres) create an interactable medium that displays spatiotemporal specific content. As an example, students can interact a hotspot to display the definition of clay masonry units (Figure 1) by clicking the associated sphere, allowing them to read the definition and observe how it relates to the digital space. Second, the (2) virtual human kinematics connects the animations, voice recordings, and spatiotemporal jobsite context to deliver a virtual tour guide the student during the visit. The set of interconnected virtual human kinematics attract the student's attention to different hotspots in the digital space and encourages exploration of the data-rich environment. Third, the (3) user interfaces for *iVisit* are contained in a virtual clipboard. The virtual clipboard is an interactive menu that enables to control the site visit progress, keep track of the learning objectives, review the spatiotemporal contents, and move to other locations. Students employ a virtual reality controller with spatial sensors, trackpad, and haptic feedback to interact with the virtual clipboard.

PILOT STUDY

A pilot study was conducted using the developed *iVisit* platform. This exploratory investigation aims to provide insights regarding the *iVisit* platform to deliver a site visit experience for students in a controlled setting. An instructional module was created to provide construction “means and methods” knowledge, specifically scoped for masonry materials. The masonry materials site visit demonstrates spatiotemporal information that cannot be shown to student in a traditional classroom, or that is difficult to be observed in a real-world jobsite (e.g., the distribution of load in a lintel from the weight of the wall, the placement and function of

vertical reinforcing bars, and the use and configuration of control joints). The site visit contained 360-degree panorama scenes captured with an Insta360 One® (5.7k resolution) camera. Over fifty 360-degree images were collected in two 2-hour sessions from a real-world fire station site primarily composed of masonry construction. Three 360-degree image scenarios were specifically selected to illustrate masonry construction processes and materials at the fire station. In the digital jobsite, a virtual human narrated the guided tour of the location describing details on each of the scenarios. Masonry educational content was developed based on the spatiotemporal context presented on each of the scenarios in the digital construction jobsite (Figure 1).

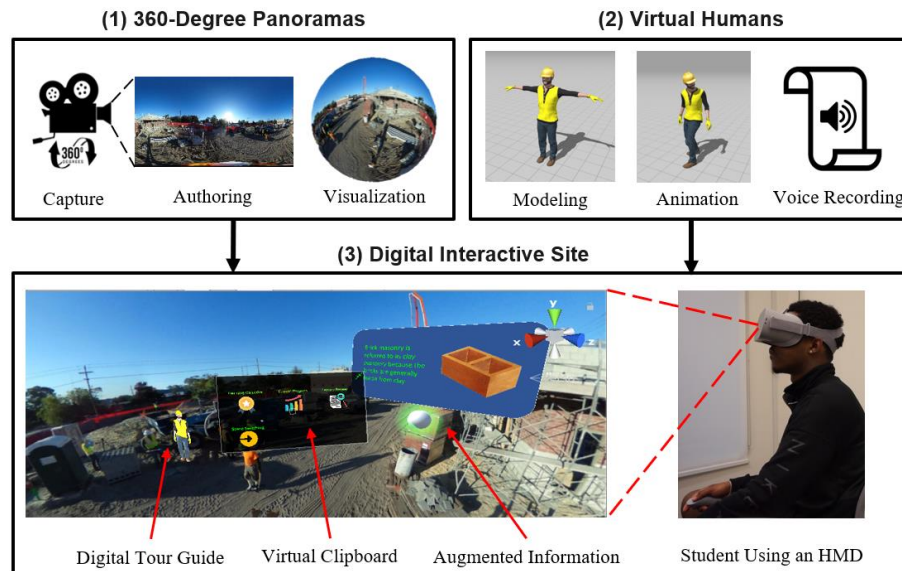


Figure 1. *iVisit* – Digital interactive construction site visits

Experimental Methodology: In order to evaluate the *iVisit* platform, students were recruited under an approved IRB protocol (#201801728) to participate in the study. Two introductory level construction courses were selected on the Summer of 2019 to recruit participants in the Rinker School of Construction Management at the University of Florida – “*BCN1210 Construction Materials*” and “*BCN1582 International Sustainable Development*”. The students experienced the digital site visit using an Oculus Go HMD in a controlled laboratory. Individual experimental sessions in a laboratory setting were scheduled for each participant, lasting for a total 35-minutes approximately. These sessions allowed the researcher enough time to perform the consent process, expose students to the *iVisit* platform, and administer data collection surveys. Before exposing the students to the experimental conditions, 10-minutes were used to describe the experiment to the participants, the rewards, and risks of the experiments as part of the consent protocol. Within that time, a demographic questionnaire was also distributed to the participants, collecting their educational level, previous construction work experience, and their familiarity with virtual reality and 360-degree panoramas. Additionally, a printed paper-based set of instructions were provided to the students that showed the different interface functions within the *iVisit* platform. Subsequently, students experienced *iVisit* within the HMD for approximately 15-minutes. During the initial 2-minutes of the *iVisit* exposure, the research team further described the interface by verbally asking the participants to use the different options available to them. The students then proceeded with the virtual human-guided site visit for approximately 13-minutes. Upon finishing the digital site visit, students removed the HMD and spent 10-minutes

responding to a series of surveys. The survey instruments contained the study measures described in the following section. Finally, the students were debriefed by the research team, answering any questions regarding the platform, the experiment, and the data collection.

Study Measures: This investigation employed three distinct post-exposure study measurements to evaluate the *iVisit* platform: (1) usability, (2) presence, and (3) student knowledge. First, the (1) usability metric was adapted from the “*System Usability Scale*” – SUS Usability – (Brooke 1996). This metric has been previously applied to virtual environment settings (Ma et al. 2019), assessing the perception of the study participants in terms of ease of use, satisfaction, effectiveness, and efficiency of system design (Brooke 2013). The survey was presented to students using a 5-point Likert scale that contained ten questions scaled from strongly disagree to strongly agree. The usability score was computed by inverting the score of negative statement questions, compounding the all the scores, multiplying the resulting score by 2.5 (Brooke 1996), and normalizing the scores (ranging from 0 to 100). SUS usability benchmarks have shown that the average score of a system approximates 68 in the scale (Sauro 2011).

Additionally, the overall experimental process was video recorded to further collect quantitative (e.g., verbal comments, platform utilization, and system errors) data regarding the usability of the *iVisit* platform. Second, the (2) presence metric was adapted from the “*Slanter, Usuh, and Steed Questionnaire*” – SUS Presence – (Slanter 1996, Usuh, et al. 2003). This metric evaluates how study participants felt when they experienced the jobsite scenes in terms of realism and immersion. To measure presence, a 5-question Likert scale instrument was used that contained a 5-point Likert scale for participants to rank their experiences in the virtual environment. To compute the presence score, responses were aggregated (bounded between the min:5 and the max:25 points) and normalized from a 0 to 100 range. An open-ended section was contained in this section for students to provide written comments. Finally, the (3) student knowledge metric measured the student learning of the contents presented in the virtual site visit. A series of questions were presented to the students and later scored by the research team. Three knowledge questions were created based on the narrated tour of the site. The question covered masonry unit part identification, differentiation between nominal and specific masonry unit dimensions, and mix proportions for the workability of masonry mortar. Partial credit for the student’s answers was awarded. The total student score was computed by adding the question scores (bounded between the min:0 and the max:6 points) and normalized from 0 to 100 similarly to the other metrics.

Results and Discussion: A total of ten students (eight males and two females) participated in the study. The participants had an average age of 20 years (Standard Dev. = 3.4 years). Most of the students were in their freshman (60%) or senior (40%) year, majoring in architecture, engineering, or construction programs (70%). A large proportion of the participants stated to have no previous construction management work experience (80%). Overall, participants reported having some knowledge of virtual reality (50%) and 360-degree panoramic imaging (60%).

An analysis was performed on the survey responses of the participants using descriptive statistics (Table 1). Students reported an average SUS Usability score of 86% (Standard Dev. = 8.8%; Maximum = 95%; Minimum = 66.7%). The score obtained was above 68%, which is the benchmark for average system performance (Sauro 2011). This result indicates that the *iVisit* platform usability score achieved high usability levels in terms of student satisfaction and ease of use for the virtual site visit experience. Nevertheless, students’ open-ended comments offered

suggestions to further improve the user-interface, mainly indicating that the virtual clipboard could be improved by “*centering on the screen instead of slightly to the left, enhancing visibility when needed*”. Additionally, after analyzing the video recordings, it was noticed that a few platform errors appear during the interactions with the hotspots (e.g., attentional arrows not disappearing, highlighting not changing color, or augmentation transferring from one scenario to another). These errors distracted students from the tour and potentially hindered their learning of information while the virtual human narrated the elements in the spatiotemporal context.

Students reported an average SUS presence score of 68.4% (STD = 14.4%; Max = 88%; Min = 36%). This presence score indicates that students perceived a high level of realism and immersion during the virtual tour. However, a student’s few comments stated that the experience could be improved by providing “*clearer graphics*” within the augmentation diagrams in the 360 images for better readability. Video recordings also support these findings, as some students were observed to attempt reading the augmentations but could not achieve that due to low image resolutions. Additionally, several students indicated that realism and immersion were affected by 360-degree images being “*blurry*”, reducing the feeling of being in real site.

Table 1. Descriptive Statistics for Study Metrics.

Quantitative Variable	Study Metrics		
	SUS Usability	SUS Presence	Student Knowledge Score
Mean (%)	86.0	68.4	31.7
Standard Dev. (%)	8.8	14.4	25.4
Maximum (%)	95.0	88.0	66.7
Minimum (%)	66.7	36.0	0.0

Finally, the knowledge scores revealed that most students correctly answered one of the three (31.7%) question in the survey assessment (STD = 25%; Max = 66.7%; Min = 0.0%). After examination of the recordings, the research team noticed these issues were caused by to the low augmentation image quality that corresponded to the knowledge questions, making them unreadable within the HMD and resulting in participants failing to correctly answer some of the questions. This outcome suggests that students within the virtual experience do not only rely on the narration of the events by the virtual human but also employ visual aspects in the spatiotemporal context and the augmentations for learning. It is important to highlight that all the student that did not major in architecture, engineering, or construction could not answers any of the questions, as they indicated that visit contained “*too many technical terms*”. However, these students’ feedback in terms of usability and presence was consistent with the other students that had majored in architecture, engineering, or construction.

RESEARCH LIMITATIONS

The pilot study presented for the proof-of-concept *iVisit* platform in this investigation exhibited limitations in three areas: (1) sample size, (2) knowledge content, (3) image quality. First, due to the exploratory nature of the research the (1) sample size of data collected was small. This eliminates the possibility to provide statistical generalizations over the whole population of study in terms of presence and learning. However, the sample size is appropriate for usability studies, as research has revealed that 10 participants can identify up to 95% of the problems in software tools (Faulkner 2003). Second, the scope of the (2) knowledge content for the study is limited. The topics covered were based directly on the spatiotemporal context

recorded in only three images, which translated into only demonstrating masonry construction concepts. Finally, the (3) image quality of both 360-degree panoramas and augmented pictures was low for HMD applications. Several students indicated that some of the content was difficult to observe due to the reduced resolution of the images, which made them rely on the narration presented by the virtual human exclusively to understand the learning materials.

CONCLUSION AND FUTURE STUDY

Site visits are a pivotal part of construction management curriculums to provide experiential learning to students. However, these spatiotemporal contexts are often inaccessible, dangerous, or expensive to reach due to many educational, institutional, or safety-related challenges. Digital site visits have been used as an alternative to real-world physical exposures to construction jobsites. One growing area of investigation within the use of virtual field trips is 360-degree panoramic digital sites. This study proposes a proof-of-concept interactive construction 360-degree panoramic sites powered by virtual humans – *iVisit*. The steps necessary to develop a digital construction site visit are presented, and a student learning session for masonry materials was implemented as a pilot study. The pilot study assessed the performance of *iVisit* in terms of usability, presence, and student knowledge. It was found that the *iVisit* platform was above average in terms of usability (Mean = 86%; STD = 8.8%), indicating that students perceived it as easy to use. Furthermore, students perceived the virtual tour as realistic and immersive (Mean = 68.4%; STD = 14.4%). However, students suggested that user-interface and image quality changes within *iVisit* were necessary to improve the overall experience. Finally, student knowledge scores showed that participants were only able to answer one-third (Mean = 31.7%; STD = 25%) of the presented questions due to low image quality in the 360-degree captures and augmentation pictures.

Future studies require a larger sample size to assess the student's responses with in-depth statistical analyses. Additionally, students from a more diverse selection of course – junior and senior – must be sampled to get a better understanding of how *iVisit* operates at different knowledge levels. Other knowledge modules (e.g., wood, concrete, or steel construction) and instructional areas (e.g., facility operations, mechanical, electrical & plumbing, or sustainable construction) should also be studied to evaluate the effect on learning using digital interactive *iVisit* sites. Finally, other instructional strategies (e.g., collaborative, cooperative, or problem-based learning) should be explored within the *iVisit* platform to further understand the capabilities of the proposed approach.

ACKNOWLEDGEMENT

This material is based upon work supported by the National Science Foundation under Grant No. 1821852. The research team would like to thank Kelvin Dover Jr. and Zhe Gao from the University of for their help with the technical development of the *iVisit* platform.

REFERENCES

- Blinn, N., Robey, M., Shanbari, H., and Issa, R.R.A. (2015). "Using Augmented Reality to Enhance Construction Management Educational Experiences". Proceedings 32nd CIB W078 Workshop, Eindhoven, The Netherlands, 8 pp.
- Eiris, R., and Gheisari, M., (2018-a) "Site Visit Application in Construction Education: A Descriptive Study of Students' Perspectives". 54th ASC Annual International Conference,

- Minneapolis, MN.
- Forsythe, P. (2009). "The Construction Game: Using Physical Model Making to Simulate Realism in Construction Education". *J. for Edu. in the Built Environment*, Vol. 4, Iss., 1, pp. 57-74.
- Kajewski, S. (1999). "Virtual construction site visits via the World Wide Web". In *Australasian University Building Educators Association Conference, Proceedings of the 3rd. & 4th Electronic Conference* (pp. 125-129).
- Mutis, I (2018). "Spatial-Temporal Cognitive Ability: Coupling Representations to Situations and Contexts for Coordinating Activities in the Construction Project Environment". *Transforming Engineering Education: Innovative Computer-Mediated Learning Technologies*. American Society of Civil Engineers, Chapter 2, pp 5-25.
- Eiris, R., and Gheisari, M. (2017-a) "Site Visit Application in Construction Education: A Descriptive Study of Faculty Members". *International J. of Cons. Edu. and Research*.
- Goedert, J. D., and Rokooei, S. (2016). "Project-Based Cons. Edu. with Simulations in a Gaming Environment". *International J. of Construction Education and Research*, 12:3, pp. 208-223.
- Wang, X. and Dunston, P. S. (2007). "Design, strategies, and issues towards an augmented reality-based construction training platform". *ITcon*, (12): 363-380.
- Rosenman, M., Merrick, K., Maher, M. L., and Marchant, D. (2006). "Designworld: A Multidisciplinary Collaborative Design Environment Using Agents in A Virtual World". *DCC, Sydney, Australia*, pp. 695-710, doi: 10.1007/978-1-4020-5131-9_36.
- Castronovo, F., Van Meter, P. N., Zappe, S. E., Leicht, R. M., and Messner, J. (2017). "Developing problem-solving skills in construction education with the virtual construction simulator". *International J. of Eng. Edu.*, 33(2), 831-846.
- Anderson, A., and Dossick, C.S. (2014). "Avatar-Model Interaction in Virtual Worlds Improves Distributed Team Collaboration through Issue Discovery". *Computing in Civil and Building Engineering*, pp. 793-800.
- Eiris, R., and Gheisari, M. (2018-b). "Building Intelligent Virtual Agents as Conversational Partners in Digital Construction Sites". *Construction Research Congress*, pp. 200-209.
- Bourke, P. (2014). "The Panorama: Applications to Science and Heritage Visualization". *Lawrence Wilson Art Gallery, Web*. <<http://paulbourke.net/papers/lawrencewilson/>>.
- Pham, H.C., Dao, N., Pedro, A., Le, Q.T., Hussain, R., Cho, S., and Park, C. (2018-a). "Virtual Field Trip for Mobile Construction Safety Education Using 360-Degree Panoramic Virtual reality". *International J. of Eng. Edu.*, Vol. 34, No. 4, pp. 1174-1191.
- Kim, J.S., Leathem, T., and Liu, J. (2019). "Comparing Virtual Reality Modalities and 360°Photography in a Construction Management Classroom". *55th ASC Annual International Conference*, Denver, CO.
- Taylor, J.E., Alin, P., Comu, S., Dossick, C.S., Hartmann, T., Mahalingam, A., and Mohammadi, N. (2018). "CyberGRID: A Virtual Workspace for Architecture, Engineering, and Construction. *Transforming Engineering Education: Innovative Computer-Mediated Learning Technologies*". American Society of Civil Engineers, Chapter 10, pp 291-321.
- Brooke, J. (1996). "SUS-A quick and dirty usability scale". *Usability evaluation in industry*, 189(194), 4-7.
- Ma, J., Jaradat, R., Ashour, O., Hamilton, M., Jones, P., and Dayarathna, V. L. (2019). "Efficacy Investigation of Virtual Reality Teaching Module in Manufacturing System Design Course". *J. of Mechanical Design*, 141(1), 012002.
- Brooke, J. (2013). "SUS: a retrospective". *Journal of usability studies*, 8(2), 29-40.

- Sauro, J., 2011, "Measuring Usability With the System Usability Scale (SUS)," MeasuringU, Denver, CO, Web. < <https://measuringu.com/sus/>>.
- Slater, M., Usoh, M., Steed, A., 1994. "Depth of Presence in virtual environments". Presence Teleoperators Virtual Environ. 3, 130-144.
- Usoh, M., Catena, E., Arman, S., Slater, M., 2003. "Using presence questionnaires in reality". Presence Teleoperators Virtual Environ. 9, 497-503.
- Faulkner, L. (2003). "Beyond the five-user assumption: Benefits of increasing sample sizes in usability testing." Behavior Research Methods, Instruments, & Computers 2003, 35 (3), pp. 379-383.