iVisit-Collaborate: Online Multiuser Virtual Site Visits Using 360-Degree Panoramas and Virtual Humans

R. Eiris[a] and M. Gheisari[b]

[a]Department of Civil, Environmental, and Geospatial Engineering, Michigan Technological University, USA
[b]Rinker School of Construction Management, University of Florida, USA
E-mail: reiris@mtu.edu, masoud@ufl.edu

Abstract –

Construction professionals need to understand collaboration within the context of jobsites. Consequently, many construction programs utilize learning activities to enable student learning of collaboration. One of those key learning activities used by construction programs is site visits. Although site visits are greatly beneficial for students, these present several challenges to be completed. This study centers on developing and testing a multiuser online system to support student learning of collaboration within the context of site visits. A case study virtual site visit was completed with 14 student dyads to understand collaboration in terms of teamwork perception, spatial visualization, and knowledge retention. It was found students perceived iVisit-Collaborate as a medium that supported effective teamwork with scores greater than five on a 7-point Likert scale. Furthermore, it was noticed the average student score 42% in spatial visualization and 64% in knowledge retention. However, it was observed that spatial visualization was not correlated to knowledge retention.

Keywords –

Site Visits; Collaboration; 360-degree Panoramas; Virtual Reality; Construction Education

1 Introduction

Construction professionals are required to collaborate with diverse stakeholders to complete any project [1]. Typically, construction educational programs utilize classroom exercises to enable students to practice collaboration [e.g., 2,3]. Although classroom exercises have been shown to be effective for teaching collaboration in-class, there are existing limitations linked to the lack of exposure to the spatiotemporal contexts where construction operations occur [4,5,6]. Learners require the use of spatial, temporal, or social contextual information (e.g., a certain space, changes with time, and interactions with peers) associated with a specific site to learn collaboration in the context of the construction disciplines. Consequently, site visits are a common method used within construction curricula to offer opportunities for learning collaboration within the context of construction jobsites [7]. However, site visits have severe limitations to be completed within the traditional construction curricula. Standardized curricula, limited financial resources, and strict class schedules introduce challenges for an educational organization, program managers, and instructors to integrate this type of learning methodologies [5] These challenges that exist in face-to-face classroom instruction become intensified when remote online learning delivery methods. Learners that are geographically dispersed pose blockades for learning collaboration – impossible to reach locations disconnect the student from the context and cause reductions in satisfaction, motivation, and overall learning [8]. Remote learning challenges have become prevalent during the COVID-19, where students were not allowed to perform face-to-face activities for safety reasons. These deficiencies in online learning result in student difficulties to learn collaboration common in today's construction professional workforce.

To address the issues associated with real-world site visits and remote instruction, virtual environments have been employed to create educational spaces for learning collaboration. Virtual environments are defined as the 3D rendered representation of construction jobsites that enables students to explore the virtual locations and control digital objects [9]. As part of these simulated construction sites, often construction professionals are represented as virtual humans (embodied depictions of experts that contain digital knowledge) [10]. These digital environments that contain expert virtual humans have been utilized in educational construction applications such as work coordination [11], building design [12], safety awareness [13], and scheduling and planning [14]. Within these educational applications, researchers have found that virtual environments offer opportunities for students to learn collaboration similarly to real-world settings. Virtual environments that utilize virtual humans create efficient communications channels between students [14], enhance student feeling of presence [15], and student knowledge exchange [16]. However, effective collaboration within these digital settings is constrained by the realism offered to portray construction jobsites. Researchers point to the lack of realism as a major limitation for current virtual environments, as students experience a reduced feeling of being present at the construction site [16,17]. Existing 3D modeled digital environments require high computational power and large time commitments to create close-to-reality simulations of the construction site [18]. Furthermore, it has been found that students that learn in unrealistic simulations do not perform with the same proficiency as they do in the real world [19]. An increasingly utilized reality-capturing technique to address the realism constraints of virtual environments is 360-degree panoramas. These easy-to-capture illustrations of reality offer an unobstructed view of a location with a high sense of "being at the present" produced by the high sense of realism [20].

This study aims to address the current limitations for virtual environments by creating a multiuser virtual site visit system – iVisit-Collaborate – using highly realistic 360-degree panoramas and interactive virtual humans. iVisit-Collaborate offers opportunities for instructors to perform virtual site visits to enable students' learning of collaboration within the spatiotemporal contexts of construction jobsites while removing the inherent challenges in these types of location-dependent interventions. A case study virtual site visit was completed by student' dyads using iVisit-Collaborate within a developed online learning system. Student teamwork perceptions, spatial visualization, and knowledge retention were collected and analyzed to understand how iVisit-Collaborate supported the learning of collaboration within online site visits. The contribution of this study centers on better understanding how multiuser systems can be used to learn contextualized collaboration within the educational constraints of classroom instruction.

2 Background

Researchers have leveraged the realism embedded into 360-degree panoramas to represent real-world jobsites across multiple educational applications. For example, Gheisari et al. [21] employed 360-degree panorama technologies to demonstrate free-body-diagrams of structural elements within building structures. Students using the 360-degree panoramas could understand the building structure without having to visit the construction jobsite. In another study, Eiris et al. [22] developed a system for students to learn hazard identification using 360-degree panoramas. Within this system, students used augmented 360-degree images with text, signifiers (e.g., arrows, circles, lines), and audio to learn safety contents. In a follow-up study, Eiris et al. [23] found that the hazard identification index for trainees that learned about multiple fall hazards (e.g., unprotected edges, floor openings, ladders) was 52% using the system. More recently, 360-degree panoramas have been used to offer virtual site visits to students. Eiris et al. [24] created a platform to offer students replicable, interactive site visit experiences guided by a virtual human. The platform was further developed to enable problem-solving opportunities within the context of the construction jobsite for students in-class [24]. The researchers found that using 360-degree panoramas for site visits significantly increased the student development of problem-solving skills by allowing direct observation of the spatiotemporal context of the jobsite. In another recent study, Eiris et al. [25] evaluated a multiuser 360-degree panorama-based environment to understand collaborative problem-solving behaviors in students. It was found that collaborative and problem-solving behavior occur sequentially and that discussion engagement was critical for collaboration. Although some studies have explored the use of 360-degree panoramas as a tool to offer realistic site visits for problem-solving and collaboration [e.g., 7, 24, 25], many aspects of collaboration within these digital experiences remain largely unexplored.

3 Research Goals and Point of Departure

The goal of this study is to understand how iVisit-Collaborate supported the learning of student collaboration. This study builds on the system development and the outcomes of prior studies [7,24,25] that have explored virtual site visits for student learning of problem-solving and collaboration. The point of departure of this study is to study how students perceived their teamwork performance while using such systems. Moreover, the relationship between student knowledge retention and spatial visualization during collaborative activities was also explored. The following subsections of this study describe the development of iVisit-Collaborate, a case study where the system was tested, and the results as the outcome of the student collaborative learning activities.

4 iVisit-Collaborate System Development

The iVisit-Collaborate system was developed using the Unity® game engine and the Photon® networking engine. These game engine software support the creation of multiuser site visits for students to collaborate online. Although the Unity® game engine supports multiple platforms for implementing software (e.g., head-mounted displays, mobile devices, desktop computers), this study selected desktop-based computers to enable access to students to the systems during the COVID-19 pandemic. Figure 1 shows the three main components included in iVisit-Collaborate. The following subsections contain a description of those components.

Figure 1. iVisit-Collaborate Platform Components

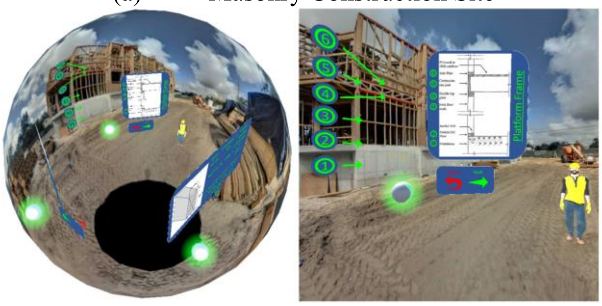
1. *Spatiotemporal Contexts:* Construction spatiotemporal contexts were used to demonstrate ideas and concepts to students in the virtual environment. The creation process of these spatiotemporal contexts required the use of 360-degree panoramas. The 360-degree panoramas were captured from real-world construction sites using commercially available 360-degree cameras (e.g., Insta 360 One X2, Ricoh Theta V) and their associated software. Using these 360-degree panoramas from real-world construction sites as background, text, objects, sounds, or signifiers were used as augmentations to clearly demonstrate information to students within the Unity® game engine.
2. *Virtual Humans:* Virtual humans were used to provide students an expert guide within the augmented 360-degree panorama spatiotemporal contexts through the use of audio narrative descriptions. There were three major components of the virtual human: a 3D digital representation, animations, audio voicings. The 3D digital representation was created using software such as Adobe's Fuse CC® or Unreal's Metahuman Creator. These software packages allowed to create a geometrical representation that embodied real humans in the digital space and animations to match the human reaction to speech or communication (e.g., facial expressions, body movements). Voice recordings were created using IBM Watson®'s text-to-speech tools for the audio voicings. This process produced audio files that contained the narrations required from the expert construction professionals. These three components were combined into the Unity® game engine to make a cohesive representation of humans as a construction professional tour leader within the virtual site visit.
3. *Online Multiuser Interaction Affordances:* Interaction affordances were developed for the iVisit-Collaborate desktop-based online application. Within the online multiuser platform, students interacted using a keyboard-and-mouse interface with each other, the spatiotemporal contexts, and the virtual humans. Color-coded laser pointers affordances were used for student communication, enabling each student to point at locations, objects, or augmentations within the 360-degree images. In addition to the pointers, two interactable objects were offered to the students – hotspots and clipboards. Hotspots served as a hub for activating augmentations and directing the attention of the students. Upon clicking a hotspot, the virtual human walked towards it and provided descriptions that matched the augmentations superimposed to the 360-degree panoramas. Clipboards served as a support affordance for student information management, keeping track of the learning objectives for the specific location, showing a transcript of the audios narrated by the virtual human, and displaying a map of the site with the locations of the 360-degree panoramas.

5 Case Study – Masonry and Wood Multiuser Construction Virtual Site Visits

To evaluate how the created iVisit-Collaborate system supported the learning of student collaboration, a case study was created for a Construction Techniques (BCN3224) class at the University of Florida. This class teaches students the principles of construction methods and techniques. The focus of this class is the basic understanding of vertical construction processes that includes topics such as masonry construction, wooden platform frame construction, cast-in-place and pre-cast concrete construction, and steel erection. Site visits to active jobsites are often used within this class to deliver active hands-on activities, facilitating the learning of spatiotemporal-dependent topics. The visits for the class are planned on a semester-by-semester basis, depending on location availability. However, due to the COVID-19 pandemic, these site visits were canceled. iVisit-Collaborate enabled the delivery of these site visits using an online multiuser format.

From the topics covered in this class, two site visits were selected by balancing topic simplicity, ease of visualization, and recommendations from the class instructor. The two topics selected were masonry and wood construction. For the masonry site visit, a masonry fire station construction site was used (Figure 2-a). Within this masonry site visit, students obtained an understanding of what are clay and concrete masonry units and the techniques required to build and reinforce masonry walls. The virtual human within the masonry site visit offered expert knowledge regarding the construction materials (e.g., nominal/actual sizing, grout composition) and the means and methods of construction (e.g., joint reinforcement, expansion joints). For the wood site visit, a commercial multifamily residential platform frame building was used. Within this wood site visit, students observed the materials installed on-site (e.g., lumber, plywood, OBS panels) and the techniques to construct the platform frame structure. Similarly, the virtual human served as an expert construction professional that described the process of building floors, walls, and roofs structures within the site.

(a) Masonry Construction Site



(b) Wood Construction Site

Figure 2. Case Study Construction Virtual Site Visits

Data collection: This study was conducted remotely, using a set of online Zoom® videoconference meetings throughout three weeks (under IRB201903043). Students completed the virtual site visits in pairs or dyads. Upon completing the iVisit-Collaborate platform experience, the students individually completed a set of four surveys using Qualtrics®. The following paragraphs provide the details for each of these surveys.

Demographics: This metric aims to understand the student background information, including age, sex, years in the construction program, experience in construction, and familiarity with virtual reality, 360-degree panoramas, construction materials, and construction techniques. A 7-question survey was used to collect this metric.

Teamwork Experience: This metric aims to understand the students' perspective regarding team effectiveness during the iVisit-Collaborate virtual site visit. A 40-question survey was used to collect this metric. The survey was adapted from the "Team Learning Beliefs and Behaviors" validated survey, developed by Van de Bossche et al. [26] to understand team learning for successful collaborations. This survey contains 28-question items to explore the social process of knowledge building within the iVisit-Collaborate. The Likert-scale questions use 7-points granularity (1-Strongly Disagree to 7-Strongly Agree) to evaluate the students' level of agreement with statements that relate collaborative learning, individual beliefs, and interpersonal contexts as part of the fundamental knowledge building process for effective teamwork.

Spatial Visualization: This metric aims to measure the student's ability to visualize objects from different perspectives in three-dimensional space using their imagination [27]. Within the context of iVisit-Collaborate, this metric measures the ability of students to envision objects on the 360-degree panorama virtual environments. For this study, Vandenberg & Kuse's [28] Mental Rotation Test was used. The Mental Rotation Test requires students to select the two correct rotations of a depicted object from four possible responses. Positive credits are assigned to correct answers, and negative credits are assigned to incorrect answers, reducing the guessing effect from the participants. A total of twenty mental rotations were done by the students. As a result of this metric, a spatial visualization score was obtained that represented the ability of students to perform mental rotations. The mental rotation score was computed individually for each student, ranging from 100% (no errors and all twenty rotations done correctly) to 0% (all twenty rotations done incorrectly or multiple incorrect rotation done that reduced the score to zero).

Knowledge Retention: This metric aims to measure the student's obtained knowledge from the iVisit-Collaborate virtual site visit. A 10-question test was used to collect this metric. The test mimics the type and scope of the questions contained in a typical class quiz for "BCN3224 – Construction Techniques". Previous quizzes utilized in this class were reviewed and adapted to develop this data collection tool. The scope of test contents was adjusted to match the information delivered through the iVisit-Collaborate site visit. From the ten questions contained in the knowledge retention test, five related to the masonry module and five related to the wood module. For each topic, one concept recall question, fill-in-the-blank question, one multiple section question, and two open-ended questions were completed by the students. The questions were graded, and partial fractional credits were awarded for the fill-in-the-blank and open-ended questions when when partially correct answers were provided by the students. As a result of this metric, a total knowledge retention score across the masonry and wood was obtained for each individual student. The knowledge retention score ranged from 100% all ten question correctly responded) to 0% (zero questions correctly responded).

5.1 Results and Discussion

In this study, a total of 14 dyads of students completed the iVisit-Collaborate virtual site visits. Students had an average age of 21 years (standard deviation: 0.7), with a high percentage of being male (82%). Over 50% of the students had low or no experience in the construction industry. Overall, a large proportion of students had no to low experience with virtual reality (no experience: 7%; low experience: 50%) and 360-degree panoramas (no experience: 4%; low experience: 60%). Contrary, most students reported having medium to high experience with construction materials (medium experience: 29%; high experience: 50%) and construction techniques (medium experience: 33%; high experience: 46%).

5.1.1 Teamwork Perceptions

The teamwork survey was analysed to understand how students perceived team effectiveness during the iVisit-Collaborate virtual site visit. The scores obtained for each dimension of this survey are illustrated in Table 1. It can be observed that all scores were very positive, with overall medians around six (Agree in the Liker-scale response). In the teamwork survey, task cohesion statements were negative, which the students responded with consistently low scores. These overall patterns indicate that the students were pleased with their teamwork performance within the iVisit-Collaborate platform. Some students supported these scores in the open-ended questions by stating comments such as "*iVisit-Collaborate was overall a good learning tool and I enjoyed using it*" and "*Communication was great. No one had any problems and we worked well as a team together*".

Figure 1. Teamwork Student Perceptions

Collaboration Variable	Mean	SD
Interdependence	5.8	0.47
Social Cohesion	6.1	0.68
Task Cohesion	2.0	0.65
Psychological Safety	5.6	0.54
Group Potency	5.8	0.53
Construction	6.0	0.45
Co-Construction	6.0	0.41
Constructive Conflict	5.6	0.79
Shared Cognition	6.0	0.62
Team Effectiveness	6.2	0.55

5.1.2 Spatial Visualization and Knowledge Retention

The spatial visualization and knowledge retention metrics were analysed to investigate student performance during the iVisit-Collaborate virtual site visit. Table 2 illustrates the descriptive statistics for these tests. Spatial visualization scores indicate the student ability for performing a mental rotation, which has been associated to a better understanding of serial operations in three-dimensional spaces. It was found that students had an average spatial visualization score of 41.8% (Standard Deviation = 59.3%). These results indicate that student scores had large variances how they would be able to understand the three-dimensional space of iVisit, potentially causing differences in the student dyads' understanding of the contents during the site visit. Furthermore, the knowledge retention score averaged 63.5% (SD = 13.4%). Knowledge retention scores describe student recall of concepts from the exposure to the site conditions using the iVisit platform. These obtained results indicat that students answered correctly over half of the ten test questions for masonry and wood after experiencing the site visits. Furthermore, a correlation analysis using a Spearman Rank Correlation Coefficient as described by Spearman [29] was performed between spatial visualization score and knowledge retention score. However, no significant correlation was found between spatial visualization and knowledge relation scores. The lack of correlation found suggests that ability to visually understand the three-dimensional space is independent from the knowledge that can be recalled from from the collaborative virtual site visits.

Table 2. Spatial Visualization and Knowledge Retention Scores

Variable	Mean	SD
Spatial Visualization Score	41.8%	59.3%
Knowledge Retention Score	63.5%	13.4%

6 Conclusion, Limitations, and Future Research

This study aimed to understand the use of virtual site visits such as iVisit-Collaborate to support the learning of student collaboration. A multiuser online system was developed and a set of virtual site visits were created (masonry construction and wood construction) to test the system. A total of 14 student dyads participated in the virtual site visit, where data was collected in terms of teamwork perception, spatial visualization, and knowledge retention. It was found students perceived iVisit-Collaborate as a medium that supports effective teamwork for virtual site visits, as all scores provided were greater than five on a 7-point Likert scale. Furthermore, it was found that spatial visualization scores greatly varied across the students and that the average student scored 63% in knowledge retention.

However, it was found that spatial visualization was not correlated to knowledge retention.

This study had three major limitations, the sample size, the limited topics covered in the system, and the remote nature of the data collection. Only 14 student dyads were collected, which limits the generalizability of the results shown in this study. Additionally, only masonry and wood construction sites were virtually visited in this study. Other types of construction (e.g., cast-in-place concrete, steel) might produce different results from the ones reported here. Moreover, the relationship between the level of realism and the variables explored in this study (teamwork attitudes, spatial visualization, knowledge retention) should be further investigated. Finally, data collection was conducted online, which limited the experimental control that the research team had on the students during the virtual site visit. Potential distractions during the remote sessions might have increased the variance in the results reported. Future studies should increase the sample size and cover a broader range of topics to better understand the usage of iVisit-Collaborate. Furthermore, an experimental setting with a control or baseline condition should be completed to understand how iVisit-Collaborate compares to traditional interventions.

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