Advanced Engineering Informatics 53 (2022) 101667

Contents lists available at ScienceDirect

Advanced Engineering Informatics

journal homepage: www.elsevier.com/locate/aei

Full length article

Online site visits using virtual collaborative spaces: A plan-reading activity on a digital building site

Yuan Sun [a,*], Gilles Albeaino [a], Masoud Gheisari [a], Ricardo Eiris [b]

[a] M.E. Rinker Sr School of Construction Management, University of Florida, Gainesville, Fl 32611-5703, USA
[b] Department of Civil and Environmental Engineering, Michigan Technological University, Houghton, MI 49931, USA

ARTICLE INFO

Keywords:
Online site visits
Virtual reality
Construction education
Plan-reading
Avatars

ABSTRACT

Site visits or field trips have been a tool utilized by construction educators to engage students in active learning, assist traditional lessons, and attain stronger and deeper student learning experiences. Nevertheless, site visits present major logistical and accessibility challenges for educational institutions and instructors, reducing the number of students that have access to the benefits of such a technique. The limitations for site visits have further broadened recently, as the reality of the COVID-19 public health concerns has forced educators to move to online course delivery quickly and the majority of site visits have been canceled. The research goal of this paper is to present construction students with opportunities to enable online location-independent site visits where contextualized learning is dangerous, unsafe, or impossible to achieve. In this project, a virtual online learning environment was created to offer the affordances that provide an in-depth learning experience through collaborative communication for a plan-reading activity in a virtual space that resembles a real-world site visit to a building facility. This virtual online learning environment helped students to experience the physical and social aspects of the site visit while getting a collaborative opportunity to practice their plan-reading skills. A comparative study with a business-as-usual condition (online delivery through Zoom®) was conducted and the students' plan-reading performance and their feedback on the sense of presence, social presence, fatigue, and system usability was reported. The outcome of the study shows that such virtual collaborative site visits present unique opportunities to enable online delivery of spatiotemporal contexts of sites and offer an effective remote alternative when these learning opportunities are not available.

1. Introduction

The academic disciplines in science, technology, engineering, and mathematics (STEM) require direct observation of complex and subtle concepts to facilitate the communication of ideas between scientists and students, creating collaborative learning experiences in real-world spaces [1]. Site visits or field trips have been a tool utilized by STEM educators to engage students in active learning, assist traditional lessons, and attain stronger and deeper student learning experiences. For example, geology and petroleum engineering have used site visits to allow students hands-on experience with field techniques. The trips provide a method to develop an onsite understanding of rock properties, stratigraphy, sedimentology, diagenesis, and geological structures [2]. Aerospace engineering has used them to allow students to observe large aircraft structures subjected to severe corrosion and fatigue damage [3]. Nuclear engineering has used them to allow students to understand the societal aspects of nuclear utilization [4]. Architecture has used site visits to enhance students' understanding of cultural heritage [5]. Site visits provide a robust method to connect classroom learning to real-world situations, enable students to communicate and collaborate with other students and professionals in real-world spaces, and increase their awareness of available career options [6].

Nevertheless, STEM site visits present major logistical and accessibility challenges for educational institutions and instructors, reducing the number of students that have access to the benefits of such a technique. Educational institutions are often constrained by limited financial resources, administrative workloads, safety challenges, and legal risks in conducting site visits [7]. Teachers have serious time constraints as they are required to operate within prescribed educational curricula. Site visits create additional stresses for the student as they are required to travel to remote locations, which interferes with attendance in other classes and with other personal responsibilities that the students may

* Corresponding author.
E-mail addresses: yuansun@ufl.edu (Y. Sun), galbeaino@ufl.edu (G. Albeaino), masoud@ufl.edu (M. Gheisari), reiris@mtu.edu (R. Eiris).

https://doi.org/10.1016/j.aei.2022.101667
Received 8 December 2021; Received in revised form 15 April 2022; Accepted 6 June 2022
1474-0346/

have. Students who suffer from health problems often do not participate in these learning opportunities as it might be counterproductive for their well-being [8]. These site visit limitations have further broadened as the reality of the COVID-19 public health concerns has forced educators to move to online course delivery quickly.

This rapid transition generates challenges for students, instructors, and institutions, as the online delivery paradigm completely differs from face-to-face instruction. Traditional online-based platforms for distanced education include videoconferencing software (e.g., Zoom® and Microsoft Skype®), learning management systems (e.g., Canvas®), and emails [9]. These online tools are often intimidating, confusing, or simply frustrating for students accustomed to face-to-face learning. These tools lack part of peer-to-peer support, instructor-student and student–student interactions, and face-to-face contact of the traditional classroom [10]. There is a greater feeling of isolation and a lack of engagement between students and the instructor in current online delivery methods. Unfortunately, this “fast and furious” move to online instruction has also resulted in the majority of institutions having their site visits to physical locations canceled with no optimal alternative in their adopted online delivery methods [11]. Lacking proper site visit experiences through online course delivery methods introduces deficiencies for student exposure to attain stronger and deeper learning experiences in such collaborative learning spaces [12]. In traditional face-to-face instruction, site visits offer STEM students hands-on learning opportunities in real-world spatiotemporal contexts, enhancing their knowledge understanding, information retention, creativity, and critical thinking [2]. The challenge, therefore, is about how instructors can help students to develop such skills using online learning approaches that inherently limit authentic STEM learning experiences. In this paper, we will address these challenges by creating a virtual collaborative space where groups of students can easily and repeatedly experience site visits that were previously impossible, dangerous, or expensive to visit.

2. Related works

2.1. Site visits in AEC education

Within the spectrum of STEM disciplines, Architecture, Engineering, and Construction (AEC) education has special site visit requirements due to the dynamic spatiotemporal contexts where these fields develop their projects. For example, architecture students are allowed to visit a project to observe the design of a specific building and talk with the designers on the site. Civil engineering students can visit a high-rise project along with the structural engineers to inspect the structural elements of such a complex building structure. Or construction students can experience the perspective of crane operators as they perform joisting maneuvers. These site visits assist AEC students in observing dynamic projects onsite and reinforcing core concepts taught in class [13]. Moreover, site visits offer students opportunities to communicate with professionals, ultimately obtaining practical knowledge onsite. However, along with all the advantages of enhancing educational quality, there are many operational and logistical issues limited to the learning opportunities related to field trips [14]. Finding suitable and convenient sites is not easy. Proper visiting times are also an extra constraint in terms of the jobsite availability [7]. Furthermore, the schedules and time available for students to interact and communicate on project sites are limited [7]. Safety concerns, long distances from metropolitan areas, difficult access to the jobsites, large class size, tight class timetables, online courses, busy site management, time and resource limitations along with the support-intensive nature of site visits, which require lots of support from university and staff, are only some of the institutional challenges that limit the use of site visit [12,15,16]. These issues result in critical barriers that prevent certain students’ from having site visit learning experiences. These barriers create disparity among students, which might potentially negatively affect minorities and underrepresented groups.

These limited but significantly valuable site visit opportunities in the regular face-to-face course delivery would be harder to deliver in remote instruction using traditional online delivery methods (e.g., Zoom®, Cisco Webex®, Skype®). In a purely asynchronous distance learning environment, instructor-student and student–student communication occur in much less frequency as compared with traditional classrooms [17]. In the case of synchronous online environments, participants have chances to communicate in real-time, but these occasions mainly focus on the learning of theoretical lessons. Because of this theoretical focus, students often do not get to collaborate in team-based activities under different hands-on or spatiotemporal settings [18,19]. In addition to such limitations, lack of learning opportunities through real-world spatiotemporal contexts of site visits, when online delivery methods are employed, still remains to be addressed. To support AEC instructors to fill the existing teaching and learning gap in online delivery of site visits and provide an alternative when such experiences are not possible in traditional face-to-face instruction, virtual site visits have been used.

2.2. Virtual site visits in AEC education

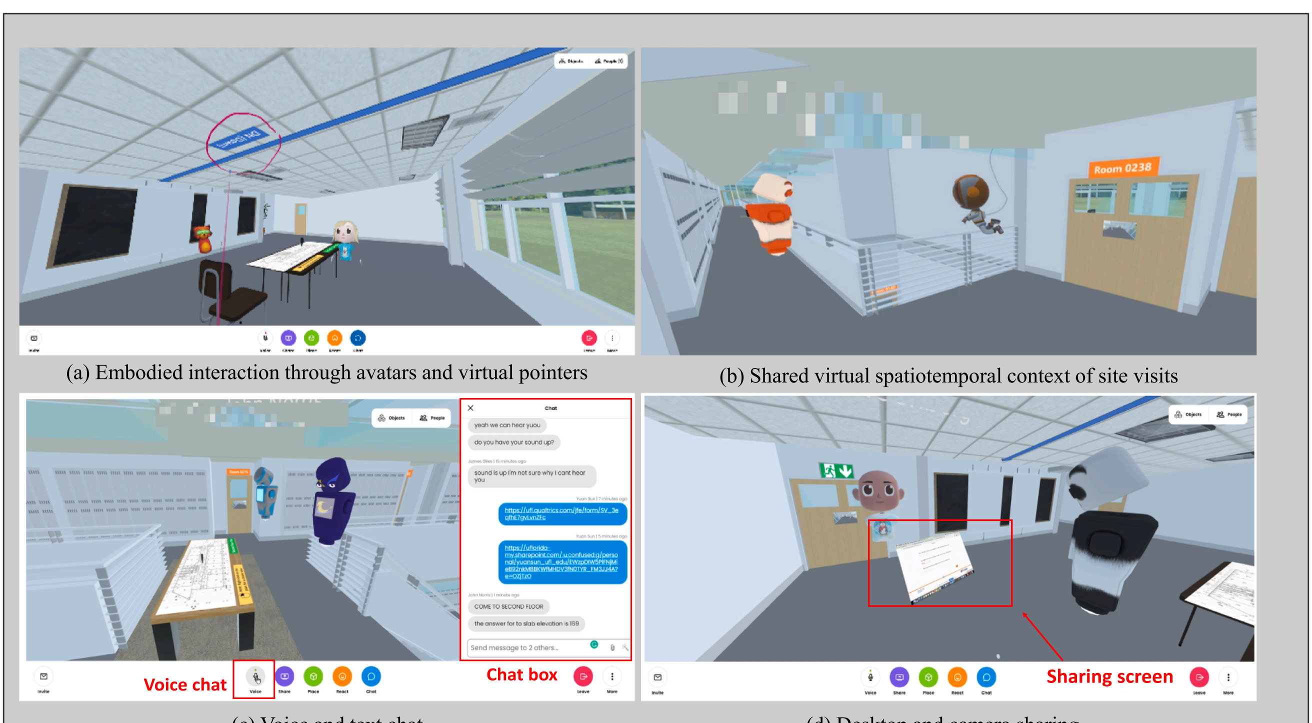
A virtual site visit is a multimedia simulation of a remote location that enables students to observe and engage with site-specific information through the use of electronic devices [20]. Virtual site visits create a learning environment in which students can avoid being physically present onsite while overcoming the spatial, temporal, and logistical obstacles inherent in traditional real-world site visits [21]. Thus, the virtual site visit is a viable educational tool that can be used in conjunction with traditional site visits or in lieu of them when they are impracticable, inaccessible, or dangerous. Due to these technological advantages, virtual site visits have been used to support students’ AEC experience, including familiarizing them with built environment disciplines, assisting them in appreciating the complexity of construction sites, increasing students’ comprehension of building structures, and enhancing students’ design review skills [7,22,23,24]. Particularly, Kandi et al. [24] designed a VR design-review game for improving students’ critical thinking and communication skills. During the experiment, the students were grouped in pairs and asked to review the design proposal of a sample building project. Moreover, Eiris et al. [25] proposed students work as pairs to complete collaborative problem-solving in a virtual site visit to understand students’ collaborative problem-solving process. Multiple methods have been investigated to properly depict jobsites digitally for various purposes. These included strategies for capturing reality through the use of 360-degree photos or videos to reveal an immersive view of an actual construction project to enhance students’ plan-reading skills [26]. Another strategy is virtual reality (VR) through the use of computer-generated simulations of reality [27]. With high levels of realism, reality-capturing technology simulates a real-world field trip, allowing students to tour genuine building sites. Virtual reality can enable students to view project sites freely and interact with different virtual entities (e.g., humans, machinery, material) on the site.

Virtual site visits offer spatiotemporal contexts of sites properly, allowing students to observe and understand construction projects; however, many students struggle to collaborate and communicate contextual information on such virtual site visits. For example, the VR-design review game, designed by Kandi et al. [24], allowed students as pairs to observe and explore the building. However, student–student collaborations were working under face-to-face conditions. One student was provided VR headsets to run the game; another student was provided a paper handout to record their data. This system provided students with opportunities to view project sites using VR technology, but distance communication and collaboration affordances still were not available. Due to such collaboration and communication barriers, virtual collaborative spaces have been explored to present digital construction jobsites with synchronous and asynchronous collaborative affordance to enhance students’ education quality [28]. For example, Building Information Modeling (BIM) and VR were combined through Second Life®– an online-based 3D environment featuring avatars [29] – to support real-time communication and interactions of users who may be geographically dispersed or may lack the modeling and analyses skills to interact within these BIM models [30]. The virtual collaborative space was also relied upon to promote experiential learning in construction safety and explore advantages associated with collaboration. As an example, [27] presented a social VR-based system which allowed students to participate in active role-playing, collaborative and dialogic learning, as well as social interaction within the 3D virtual world. After testing their system's applicability using virtual safety scenarios derived from real construction jobsite incidents, the authors showed that the system improved safety experiential learning and collaboration by enabling students to successfully identify construction problems within the environment. These digital spaces have been used to empower students' hands-on exploration and creativity [31], environment visualization, verbal and non-verbal communication [28], and ultimately, information transfer and learning [32].

Nevertheless, one of the main barriers of using virtual site visits is the hardware and software requirements that hinders their wide user reachability and accessibility. For example, the complex and large models that were used to develop a collaborative VR environment using the Unity® Game Engine [33] may cause some juddering issues (low frames-per-second rates) due to the limited hardware conditions of some users workstations [34]. In addition, some compatibility-related issues were encountered due to the environment being developed using a Unity® version other than the one that was being used by users [34]. Another study evaluating the impact of a social VR system on construction safety education indicated that students had to make additional effort to learn new skills required to be able to operate the system [27]. This is a particular concern today when COVID-19 requires social distancing and remote instruction where not all students might have access to advanced hardware and software tools to access such virtual worlds [35]. Due to such constraints, students often do not get the opportunity of experiencing such virtual collaborative spaces [36]. In this paper, we will address this challenge by creating a fully online device-agnostic experience where students can communicate and collaborate within spatiotemporal contexts of virtual site visits. Each student, along with the classmates, would access the virtual site visits on their browser simply by a link. Students would be represented with their avatars through which they would explore virtual sites. These online virtual space interactions will be further facilitated by student–student audio communication through their microphones.

2.3. Proposed pedagogical solution: Online site visits using virtual collaborative spaces

Pedagogically, our proposed online site visit is conceptualized as computer-mediated communication (CMC) and a computer-supported collaborative learning (CSCL) environment. CMC is defined as human interactions that take place by way of a computer or other electronic devices, such as video conferences, electronic and voice mails [9]. On the other hand, CSCL is defined as the intersubjective process where a group of individuals engages collectively in cognitive and metacognitive activities to build a shared problem understanding [37,38,39]. Our proposed virtual collaborative space system involves a digital space and a set of affordances with which the learner can collaboratively communicate on that online virtual space. Fig. 1 illustrates examples of how such online site visits provide virtual collaborative opportunities through a set of communication affordances. In such online site visits, students are represented in the virtual environment through their interactive avatars (Fig. 1-a). These avatars enable students to observe non-verbal communication cues (e.g., head-orientations, facial animations, hand movements) in the digital sites. Additionally, students can leverage an array of interactions that are impossible in the real-world such as highlight areas using virtual pointers (Fig. 1-a). These digital spaces are visitable by multiple students simultaneously, providing situated communication and collaboration opportunities for the students (Fig. 1-b). Students can communicate using voice and text chat (Fig. 1-c). Using spatial-aware audio, students can communicate similar to the real world, listening clearly to other students that are close by and having faded audio for students far away. Text chat can also be provided



(a) Embodied interaction through avatars and virtual pointers (b) Shared virtual spatiotemporal context of site visits (c) Voice and text chat (d) Desktop and camera sharing

Fig. 1. Different affordances within online virtual spaces.

to support alternative means of communication, enhancing flexibility and agility of the process. Students will be able to share their desktop views with their peers in real-time (Fig. 1-d). Additionally, students can share their computer camera feed to enhance communication through facial expressions.

2.4. Theoretical underpinnings

The development of such online site visits mainly revolves around two learning theories: Problem-Based Learning (PBL) [40] and the Cognitive Theory of Multimedia Learning [41]. Considering AEC students' engagement and learning outcomes, PBL theory was applied to support the online site visit learning strategy. Yew and Goh indicated that "PBL enables students to learn while engaging actively with meaningful problems. Students can obtain opportunities to problem-solve in a collaborative setting, create mental models for learning, and form self-directed learning habits through practice and reflection" [42]. The act of problem-solving focuses on using a sequence of cognitive operations with a directed goal to obtain value [43]. To solve problems, solvers collect all information available in the problem space where potential knowledge or information is provided to the solver at a given time to compose the holistic mental model [44]. The mental model is produced using the problem state and changes as the problem state changes. Furthermore, the majority of the learning process takes place in groups or teams. Personal competencies are thereby developed so that students learn to handle the process of group cooperation in all its stage. The proposed online site visits would have the potential to create a collaborative problem-solving space to develop deep thinking by providing students long periods of scaffolded, self-controlled reflection time on online site visits, interactions with peers and instructors on the spatiotemporal contexts of virtual projects, and active cognitive engagement [45–47]. In addition, the online site visit's social agency principle emphasizes the role of social cues provided via personalization, voice, image, and embodiment [48]. Integration of these cues in such collaborative virtual spaces may support the emotional engagement of students with the content and with their peers, potentially resulting in motivationally and cognitively rich collaborative problem-solving site visits [28].

This online site visit learning strategy is also supported by the Cognitive Theory of Multimedia Learning [41] Clark and Mayer [49] indicated that "Multimedia presentations can encourage learners to engage in active learning by mentally representing the materials in words and in pictures and by mentally making connections between the pictorial and verbal representations". The proposed online site visits provide various learning media, such as words, images, spatiotemporal contexts, and social cues to support students' online learning opportunities and improve students' active learning engagement through interacting with these learning media. Importantly, the online site visits can facilitate direct observation of groups' intersubjective learning [50,51] on the spatiotemporal contexts of online site visits and enable the understanding of real-world situations that are inherently context-dependent (e.g., objects, persons, and resources) [31]. Moreover, the online site visit can provide collaborative learning opportunities for heterogeneous groups [40,52], affording different group sizes of students. Students in online classes are unable to experience the physical and social aspects of these sites due to their remote locations. In such collaborative learning environments, groups of students can easily and repeatedly experience spatiotemporal occasions that were previously impossible, dangerous, or expensive to visit. The following section discusses how such a proposed virtual experience was integrated for a specific site visit activity.

3. Research goal and questions

The related works indicated the importance of site visits in AEC education and current research and applications of virtual site visits. In particular, the virtual site visits using a collaborative environment improved students' experiential learning and collaboration and empowered students' hands-on exploration and creativity. However, these virtual site visits existed several barriers, including high hardware and software requirements and compatibility-related issues due to different versions of development tools. These barriers hinder wide user reachability and accessibility. Hence, this research aims to present a fully online device-agnostic experience using virtual collaborative environment to overcome challenges associated with existing learning and teaching methods on site visits where such contextualized learning field trips are dangerous, unsafe, or impossible to visit. It leads to the following objectives: (1) building an online site visit for a plan-reading activity; (2) evaluating students' learning performance within the online site visit; (3) evaluating system usability of the online site visit. To evaluate the impact of the system on students' learning performance and understand the system usability, multiple variables were selected as study metrics. Learning performance could involve not only students' answers to plan-reading assessment but also students' mental representations, virtual environment's problem spaces and the collaborative setting. Hence, plan-reading assessment, sense of presence, and social presence would be applied for understanding students' learning performance and experience. In addition, students' satisfaction and acceptance of the technology in the virtual environment resulted from system usability. The ease of use of the system and the psychological burden it caused were related to the system usability, which would be evaluated by the system usability score and users' fatigue. Based on the above research goal and objectives, the authors sought to answer the following research questions:

(1). Does the proposed virtual online site visit lead construction students to obtain a higher learning performance, sense of presence, and social presence than a business-as-usual online video-conferencing?
(2). Does the proposed virtual online site visit provide ideal system usability and a low-fatigue experience?

The findings of the study are expected to improve the existing online site visit in AEC education by creating a clear workflow of design. This study would evaluate participants' learning performance and experience and demonstrates the online site visit as an effective device-agnostic alternative to deliver collaboratively contextualized learning in a distance construction curriculum.

4. Research methodology

The research goal of this study is to present construction students with opportunities to enable online location-independent site visits where contextualized learning is dangerous, unsafe, or impossible to achieve. Three steps were accomplished to achieve this goal (Fig. 2). First, a virtual collaborative learning environment was created using Mozilla Hubs® to offer the affordances that provide an in-depth learning experience through collaborative communication for a plan-reading activity in a virtual space that resembles a real-world site visit to a building facility. Then, a comparative study with a business-as-usual online condition (online delivery through Zoom®) was conducted and finally, the students' feedback on presence, social presence, fatigue, system usability, and their plan-reading performance was reported. Further details about those three steps will be provided in the following sections.

4.1. Site visit case study: A plan-reading activity on the spatiotemporal context of a building site

This site visit case study was conducted based on the common task of plan-reading and the need for interpreting the 2D drawings on the complex spatiotemporal context of jobsites, building projects, and

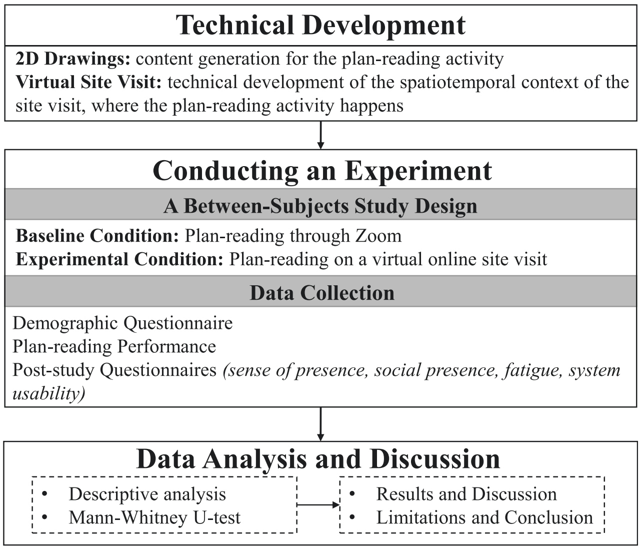


Fig. 2. Research overview.

facilities. The completion and maintenance of a construction project throughout its entire lifecycle involves massive information transfer among different AEC entities. This information transfer is conventionally accomplished through the use of 2D drawings (e.g., plan views, elevations, detailed sections), which are the only type of legally-approved design documents to display spatial relations, dimensions, details, and components of buildings [53]. Project entities communicate and collaborate by referencing these 2D drawings to understand the design intent of a particular building element [54]. Nevertheless, communicating and collaborating through the use of 2D drawings is found to be complicated and challenging, particularly for entry-level workers and graduates [55]. This encouraged different AEC educational curricula to better train AEC students on plan-reading and enhance their 2D plan interpretation and understanding skills. Such plan-reading training currently involves the cognition, perception, and visualization of objects in both 2D and 3D, in addition to conducting construction site visits [56]. However, the challenges for conducting site visits, which used to be logistics- and safety-related, have been further broadened recently with the COVID-19 situation. Such factors forced educators to significantly reduce or even cancel multiple planned site visit activities, restricting opportunities for peer-to-peer interactions and exposing students to the real-world spatiotemporal context of jobsites [57]. This limitation constitutes the focus of this study, which aims to develop a plan-reading activity in an online site visit using a virtual collaborative environment to replicate the site visit in the targeted undergraduate course (i.e., BCN 3255 Graphic Communication in Construction). The site visit was conducted in an educational facility at the University of Florida that got canceled because of COVID-19 restrictions. Even though online video-conferencing tools (e.g., Zoom® and Microsoft Skype®) were widely adopted communication mediums for online educational activities during COVID-19, online video-conferencing type of instruction has been demonstrated to be associated with negative effects on students' learning experience and motivation [58]. In an attempt to avoid reducing students' levels of engagement and motivation, and given the COVID-19 circumstances which prevented them from physically performing the site visit, we proposed an online site visit that: (1) enabled students to communicate, interact, and collaborate with each other within the same virtual space; and (2) allowed them to virtually visit an interactive 3D building, look at its components, and access the 2D drawings associated with that building.

4.2. Technical development

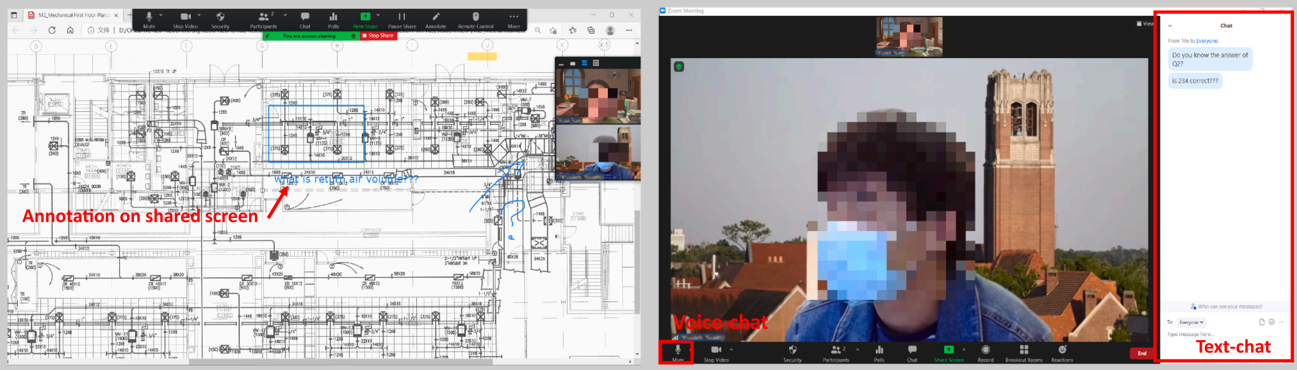
Two conditions for the above online plan-reading activity were developed: (1) a baseline plan-reading condition using 2D drawings accessed through commonly used Zoom® online communication platform (Baseline Condition) and (2) the experimental plan-reading condition on a virtual online site visit developed using Mozilla Hubs® (Virtual Site Visit Condition). For the baseline condition, students were asked to use only 2D drawings and Zoom® to complete the plan-reading task. A total of eleven 2D drawings were retrieved from a 90-page drawing set (in PDF format) pertaining to Rinker Hall, a University of Florida Construction Management educational facility. This educational facility was selected as a real-world building environment on which the virtual site visit condition was designed and developed. This facility consists of classrooms, laboratories, offices, mechanical rooms in addition to other facilities, which were not available to the students due to COVID-related restrictions imposed by the Center for Disease Control (CDC) and the University. The drawings consisted of floor plans, ceiling plans, interior elevations, mechanical plans, as well as mechanical symbols sheets. The Zoom® online communication platform was used as the baseline condition due to the following reasons: (1) it included multiple communication tools (e.g., text, video-chat, screen-sharing), enabling students to achieve basic communication and collaboration tasks without any training [59]; and (2) it has been considered as the most widely adopted communication medium for online educational and conferencing activities during COVID-19 not only within the University of Florida but also across the US [60]. During the plan-reading activity, students were able to use voice (through their workstations' microphones) and text chat tools (Fig. 3-a), in addition to sharing their video and/or computer screens, uploading files (e.g., drawings), and annotating on drawings (Fig. 3-b) to communicate and collaborate with their peers in real-time.

In the virtual site visit condition, the virtual experience was created using Mozilla Hubs® [61] because of its device-agnostic characteristic and minimum hardware and software requirement, only requiring users to have a web browser to access the virtual site visit experience [36]. In addition, Mozilla Hubs® provides customization capabilities of virtual space contents through integrating various previously-discussed affordances (e.g., embodied interaction through avatars and virtual pointers, shared virtual spatiotemporal context of site visits, voice and text chat, and desktop and camera sharing), facilitating remote collaborative tasks [62]. The virtual contents and scenes should be created or modified by Mozilla Spoke® [63], a browser-based scene editing platform for Mozilla Hubs®. This scene editing platform allows developers to explore and import different contents (e.g., images, videos, 3D models) into the scene [64]. Upon scene creation completion in Mozilla Spoke®, the virtual site visit was then published to Mozilla Hubs® and became available through a link.

Fig. 4 shows the technical development process of the virtual site visit condition. First, the 3D model of the building facility was created in Autodesk® Revit [65]. The generated 3D model in .rvt format was then exported into a .glb format using the SimLab® GLTF exporter [66]. Then the .glb file of the building model was imported to the Mozilla Spoke® to edit the 3D model and add other contents into the scenes before publishing it into Mozilla® Hubs. Students were given the freedom to use any tool in Mozilla Hubs® that would ultimately assist in their collaborative work. For example, students were able to use voice and text chat tools and drawing tools [Fig. 5(a)] to communicate and discuss with their peers. Students were also able to share 2D drawings with their peers in real-time by uploading files [Fig. 5(b)].

4.3. Conducting the experiment

A between-subjects experiment design was adopted to understand how online site visits could provide construction students with communicating and collaborating opportunities of construction-related



(a) Student-student interaction and communication in the baseline condition

(b) Sharing 2D drawings in the baseline condition

Fig. 3. Collaboration and communication affordances in the baseline Zoom® condition.

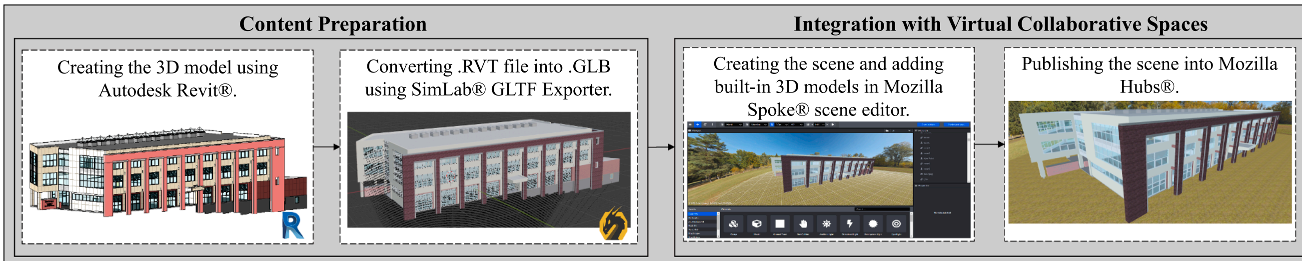
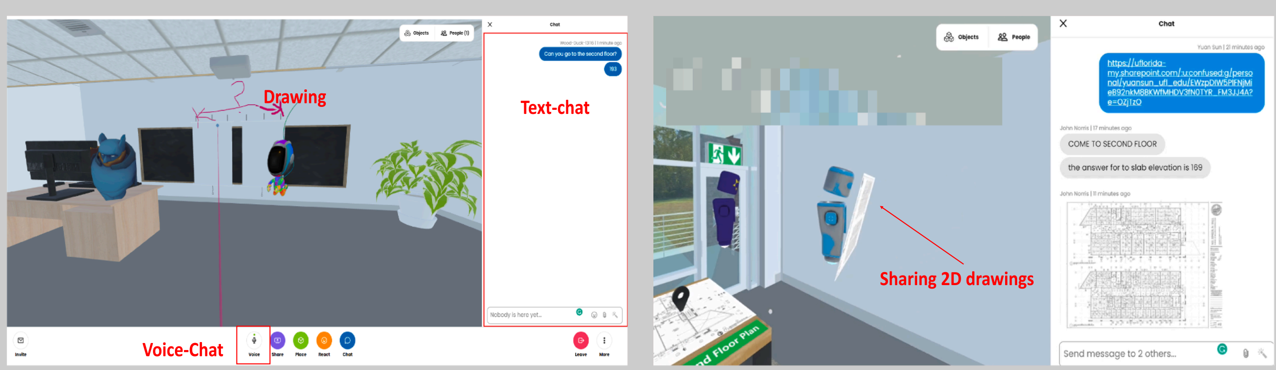


Fig. 4. The technical development process of the virtual site visit condition.



(a) Student-student interaction and communication in the virtual site visit condition

(b) Sharing 2D drawings in the virtual site visit condition

Fig. 5. Collaboration and communication affordances in the virtual site visit condition.

activities on site. The online site visit experiment replicated the plan-reading learning activities specifically designed and conducted as a collaborative task for the BCN 3255 – Graphic Communication in Construction class offered at the M.E. Rinker, Sr. School of Construction Management at the University of Florida. The plan-reading activity required students to work together to complete the tasks described in the activity. Students applied the partial information within their drawings to work in pairs to solve the presented plan-reading tasks, which were designed by the instructor in this course. The pairs would be randomly assigned 5 and 6 drawings of 11 drawings but answer the same set of plan-reading questions. In other words, students could not solve the plan-reading task unless they both worked together, as the activity was designed in a way that the information provided for both students complemented each other. This class was selected because it has a specific learning objective of being able to read, understand, and use construction documents to facilitate communication. The experiment was approved by the UF Institutional Review Board (IRB) under IRB# 202100453. Due to safety and health restrictions imposed by COVID, this class was only offered online, and the students could not have in-person access to all the spaces in the building to conduct their plan-reading activity. First, all the students participated in an online two-hour session on plan reading and worked on an individual activity toward the end of that session. Then, the students were randomly assigned to two plan-reading assessment conditions (1) Baseline Condition and (2) Virtual Site Visit Condition. Students were working in dyads to answer a series of plan-reading questions under each condition.

In addition to the plan-reading assessment that happened during the experiment, the students responded to a pre-experiment survey followed by a series of questionnaires after the experiment. All these online questionnaires were created and distributed through Qualtrics®. The pre-experiment survey mainly focused on the demographics of the respondents with questions on their age, gender, educational level and background, as well as their familiarity with plan-reading and virtual collaborative environment. The post-experiment surveys focused on various aspects of their online experience, such as sense of presence [67], social presence [68], fatigue [69], and system usability [70]. The following sub-sections will further discuss these study measures.

Plan-Reading Assessment: Students were working in dyads to answer a set of nine plan-reading questions under each condition (Table 1). The questions were discussed and approved by the course instructors and the teaching assistants to make sure they satisfied the course's plan-reading learning objectives. Task completion duration (i.e., the time difference between when students started the plan-reading assessment and submitted it) and rate of correct responses (i.e., the percentage of correct responses out of all possible answers on the nine questions) were used to evaluate students' plan-reading performance under each condition.

Sense of Presence: The effectiveness of virtual environments for engaging and motivating users is associated with the concept of presence. Presence is defined as "the subjective experience of being in one place or environment, even when one is physically situated in another" [71]. A validated 5-point Likert-scale presence questionnaire from [72] was adopted for the users to rank the spatial presence, engagement, and realism of both platforms [73,74]. The spatial presence refers to the sense of being in a physical or real place; engagement is defined as students' level of focus within the virtual environment; and realism is the extent to which the virtual environment is remembered as a real or physical place [74]. A larger value on the Likert-scale presence questionnaire indicates stronger spatial presence, engagement, and realism. The 2D plan interpretation and understanding skills involve the cognition, perception, and visualization of objects in both 2D and 3D [56]. A high-presence virtual environment supports students' understanding of information interpretation in 2D and 3D by providing the experience of being in one place or environment and allowing them to explore and observe both 2D and 3D within the virtual environment freely.

Social Presence: Social presence is defined as the extent to which subjects would have the feeling of being with their partner throughout a collaborative work [75]. A validated 5-point Likert scale questionnaire adopted from [68] was used to evaluate subjects' social presence in the virtual environments of the study conditions. This adopted social presence questionnaire included the following six collaborative-related dimensions:

(1) Co-Presence: the degree to which participants believe that they are not alone and secluded, considering collaborative users' level of peripheral or focal awareness of their partners, as well as the degree to which their partners are peripherally or focally aware of them during the collaborative activity.
(2) Attentional Allocation: the amount of attention the collaborative users allocate to and receive from each other.
(3) Perceived Message Understanding: the collaborative users' ability to understand the information received from their partners and their perception of their partners' level of information understanding.
(4) Perceived Effective Understanding: the collaborative users' ability to understand the emotional and attitudinal states of each other during the collaborative task.
(5) Perceived Emotional Interdependence: the extent to which the collaborative users' emotional and attitudinal state affects each other.
(6) Perceived Behavior Interdependence: the extent to which the collaborative users' behavior affects each other.

Fatigue: Online education and the excessive use of virtual environments and videoconferencing tools seem exhausting and might be associated with several fatigue-related implications caused by increased cognitive load, limited physical mobility, and extended periods of continuous eye gazing and video viewing at a close distance from screens [69]. With the aim of understanding how the baseline condition of Zoom® and the proposed condition of virtual site visit might differ on psychologically causing fatigues of the study participants, the recently developed and empirically validated survey by [69] was used. This survey assesses five types of general, visual, social, motivational, and emotional fatigues.

System Usability: System Usability Scale (SUS), which is a validated 5-point Likert-scale developed by [70], is a unidimensional measure to assess users' perceived usability of a system. The SUS has been broadly applied across different disciplines and areas, and multiple researchers have indicated its reliability, validity, and sensitivity to different independent variables. As application examples, SUS has been used to assess the acceptance of technology in the e-learning field [76] and to understand users' satisfaction and cognitive achievement in virtual environments [74]. The SUS would be used in this study to evaluate the quality of the user experience by specifically measuring its: (1) effectiveness (i.e., users' ability to complete tasks using the system); (2) efficiency (i.e., users' consumed level of resources when performing tasks); and (3) satisfaction (i.e., users' reactions to the system performance).

The demographic and post-experiment questionnaires were analyzed using descriptive statistics. Also, Mann-Whitney *U* test [77] was used to compare the means and look for any statistically significant differences between both conditions (i.e., Zoom® and Mozilla Hubs®), as determined by the Shapiro-Wilk normality test [78] (all, $p \leq 0.016$, <0.05).

5. Results and discussion

A total of 36 students ($N = 18$ per study condition) participated in this study (Table 2). Participants from both groups shared a very similar background, as evidenced by their demographic information. In fact, the majority of the participating students were males (75%, $N = 36$), with an overall average age of 21 ± 0.98. Most subjects were undergraduate students (86%) studying construction management (89%). The majority did not have any level of familiarity with Mozilla Hubs® (78% in baseline condition and 67% in virtual site visit condition). However, most of the subjects (72% of each condition) had a fair to a competent level of familiarity with plan-reading. This section will discuss the results of the comparative analysis between the baseline and virtual site visit conditions considering factors such as plan-reading performance, presence, social presence, fatigue, and system usability.

5.1. Plan-reading performance

The objective of this assessment was to examine how the developed virtual site visit could provide students with a plan-reading opportunity on virtual sites and compare it against the business-as-usual condition during COVID (baseline condition using Zoom®). As previously indicated, the rate of correct answers and task completion duration were used to evaluate students' plan-reading performances under both groups (Table 3). Overall, no statistically significant differences were identified between these conditions, and Cohen's D indicated the large effect of the sample size for the generalization of results for correct responses rate and task duration (2.263, 0.700, respectively). However, the results show that, on average, the virtual site visit condition had a higher rate of correct responses (76%) than the baseline condition (72%). Driven by PBL and Cognitive Theory of Multimedia Learning, the collaborative problem-solving setting, various social cues (e.g., personalization, voice, image, and embodiment), and multiple learning media (e.g., graphics, voice, 3D models, and spatiotemporal context) have the potential to assist students' understanding of plan-reading information through interacting with peers and observing both 3D models and 2D drawings within spatiotemporal context. In addition, a longer duration was required to complete the plan-reading task in Virtual Site Visit Condition

Table 1
Plan-reading assessment.

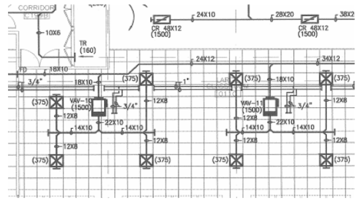
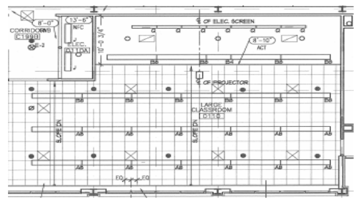
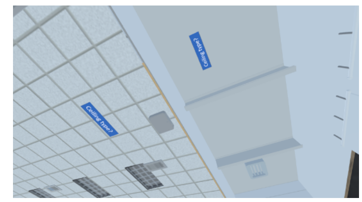
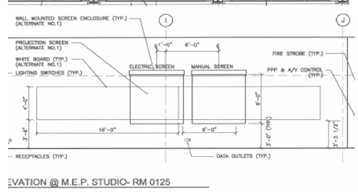
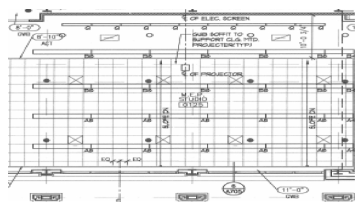
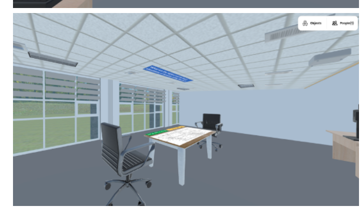
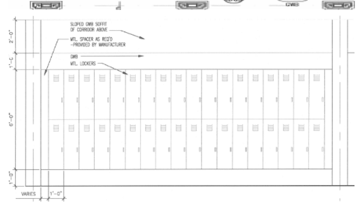
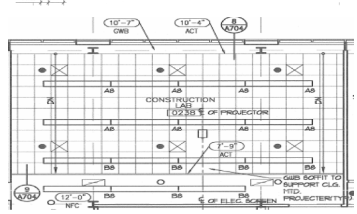
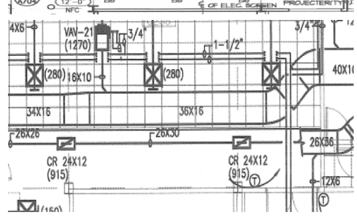
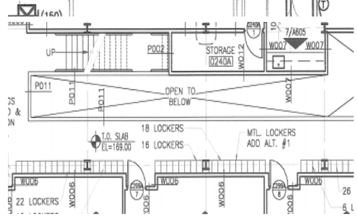
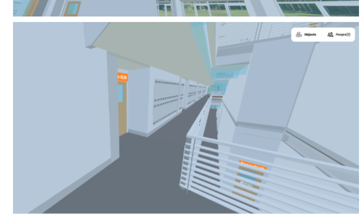
Questions	Related place of the response on the 2D drawing	Related place of the response on the virtual site
1: What is the air volume (in CFM) supplied through the diffusers in room 110?		
2: List the two types of ceilings in room 110 3: List two items (except diffusers) located on the ceiling in room 110		
4: What is the center-to-center distance between the Electric screen and the Manual screen in room 125?		
5: What are the highest and the lowest elevations of the ACT ceiling in room 125?		
6: What is the height of the lockers located in the first-floor corridor?		
7: Room 238: What does the arrows on the ceiling mean in room 238?		
8: What is the size of the return diffuser in room 238?		
9: What is the second-floor top of slab elevation?		

Table 2
Participant demographics.

Parameters		Baseline Condition Number (Percentage)	Virtual Site Visit Condition Number (Percentage)
Gender	Females	7 (39%)	2 (11%)
	Males	11 (61%)	16 (89%)
Educational Level	Undergraduates	16 (89%)	15 (83%)
	Graduates	2 (11%)	3 (17%)
Educational Background	Construction Management	18 (100%)	14 (78%)
	Other (e.g., Architectural and Civil Eng.)	0 (0%)	4 (22%)
Familiarity with Mozilla Hubs®	None	14 (78%)	12 (67%)
	Some knowledge of	2 (11%)	3 (17%)
	Fair	2 (11%)	3 (17%)
	Competent	0 (0%)	0 (0%)
Familiarity with Plan Reading	None	0 (0%)	0 (0%)
	Some knowledge of	5 (28%)	5 (28%)
	Fair	8 (44%)	9 (50%)
	Competent	5 (28%)	4 (22%)

Table 3
Results for plan-reading performance.

Variables	Baseline Condition Mean (SD)	Virtual Site Visit Condition Mean (SD)	p-value	Cohen's D
Correct Response Rate	72% (2%)	76% (1.5%)	0.466	2.263
Time (Mins: Secs)	16:26 (04:58)	21:05 (09:21)	0.071	0.700

(16:26) than Baseline Condition (21:05). Multiple factors may have contributed to this longer task completion durations in the virtual site visit condition. As a part of the virtual site visit condition, the students were required to virtually walk on the building site and spend some time exploring different rooms and reviewing different building components in the 3D virtual environment, and using the provided 2D drawings to identify the right spaces and objects that might refer to the corresponding plan-reading questions. The goal was to mimic a real experience of being on a building site and identifying different spaces or building components using paper-based 2D drawings. While in the baseline condition, the students did not get the experience of exploring the building site and were solely depending on the 2D drawings to perform their plan-reading task. It should also be noted that several technical difficulties were encountered while using the virtual site visit (e.g., missing audio, missing features or objects on the sites). The participants needed a high bandwidth and low-latency network speed to access the virtual site visit on their browser, and sometimes they had to reload or re-enter the virtual space to resolve those technical difficulties. For example, a user participating in the virtual site visit condition commented, "*I have to take a while to load into rooms and sometimes I was kicked out room*".

5.2. Sense of presence

Table 4 shows the results for the sense of presence. Specifically, participants in the virtual site visit condition experienced a significantly higher sense of being in the building (Virtual Site Visit Condition: 4.33 vs. Baseline Condition: 3.06, with a Cohen's D = 1.374) and also had significantly higher instances during which the building seemed the reality for them (Virtual Site Visit Condition: 3.28 vs. Baseline Condition: 2.50, with a Cohen's D = 0.780). When asked to reflect on their experience, participants in the virtual site visit condition also thought of

Table 4
Results for the sense of presence.

Questions	Scale	Baseline Condition Mean (SD)	Virtual Site Visit Condition Mean (SD)	p-value	Cohen's D
Please rate your sense of being in the building	Not at all (1)–(5) very much	3.06 (1.11)	4.33 (0.69)	0.000	1.374
To what extent were there times during the experience when the building was the reality for you	At no time (1)–(5) Almost all the time	2.50 (0.98)	3.28 (1.02)	0.027	0.780
When you think back about your experience, do you think of the building more as an image that you saw or more as somewhere that you visited?	Image as I saw (1)–(5) Somewhere that I visited	2.83 (1.50)	4.11 (0.96)	0.009	1.016
During the time of the experience, which was strongest, on the whole, your sense of being in the building or elsewhere?	Being elsewhere (1)–(5) Being in the building	3.44 (1.20)	3.78 (1.11)	0.381	0.294
During the time of the experience, did you often think to yourself that you were actually in the building?	Not very often (1)–(5) Very much so	2.50 (1.20)	3.28 (1.18)	0.074	0.655
Combined Responses for Overall Sense of Presence:		2.87 (1.24)	3.76 (1.07)	0.000	0.768

the building more as somewhere they had visited (4.11), significantly higher than the baseline condition, who rather thought of the building more as an image they saw (2.83), with a Cohen's D = 1.016. The other aspects, although they were not significantly different, the virtual site visit condition resulted in higher outcomes on average. But looking at the combined responses for the overall sense of presence, subjects reported a significantly higher sense of presence in the virtual site visit condition (3.76) compared to the baseline condition (2.87), with a Cohen's D = 0.768. The Cohen's D indicated a large effect of the sample size for the generation of the results. Considering the Cognitive Theory of Multimedia Learning, the incorporation of 3D virtual environments in the online site visit exposed students to real-world spatiotemporal contexts of the building that could influence students' cognitive acceleration, increase their self-management, and enhance their engagement in problem-based activities [79]. Particularly, the spatiotemporal context provided a high sense of presence, which significantly improved students' learning motivation that students were willing to explore the spatiotemporal environment and solve plan-reading problems actively. Some subjects also provided qualitative feedback on how to improve the sense of presence in the virtual site visit condition. For example, one user stated that the experience could be improved by providing a "*clearer texture of the building*" for better immersion; and another individual indicated that some visuals were "*blurry*", reducing the feeling of being on a real-world construction jobsite. The building texture blurriness might be caused by the settings (i.e., default RGB color) that were used to export the model from Autodesk Revit®, potentially limiting the environment's realism, readability, and immersion. Using actual construction material textures export settings or exporting the 3D model as generic (i.e., with no materials assigned) components prior to applying different textures using any 3D modeling software might solve this issue. Another source of blurriness could be caused by the limited Mozilla Hubs® content size, which currently restricts rendering file sizes exceeding 128 MB. This factor might affect the quality of the files being uploaded to the virtual environment, potentially resulting in low-resolution images and drawings as well as limited readability. Balancing the sizes of the 3D components, texts, images, and drawings within the environment might also improve the virtual environment's visual quality and students' sense of presence.

5.3. Social presence

Participants from both conditions indicated high levels of co-presence, believing that they neither were alone nor secluded, with users in the virtual site visit conditions (4.28) experiencing a slightly higher sense of co-presence when compared to the baseline condition (4.11), with a Cohen's D = 0.235 (See Table 5). This shows that students experienced high levels of peripheral awareness of their partners and were able to capture each other's attention during the collaborative plan-reading task. High and comparable attentional allocation ratings were also observed under both conditions, with users in the baseline condition (4.28) experiencing a slightly higher sense of co-presence when compared to the virtual site visit conditions (3.98), with a Cohen's D = 0.425. Such results highlight the high degree of attentiveness that users allocated while interacting with their partners in the plan-reading activity. One potential limitation that led to lower ratings for the virtual site visit condition could be associated with voice-related technical challenges and internet connection issues, often impairing the communication during the collaborative task. One user in the virtual site visit condition indicated that *"my partner was unable to respond to me in time due to the network delay."* Using a high bandwidth and low-latency network might resolve such technical problems, which could ultimately enhance attentional allocation in virtual site visits. Furthermore, because virtual site visits require more time to load 3D models and more content, subjects might distract from the plan-reading task during the long waiting period. A potential solution is to balance the size of the 3D models and virtual contents, reducing the virtual site loading time. Subjects in both conditions had relatively high perceived message understanding ratings, which show they were capable of understanding the information received from and perceived by their partners during the task (baseline condition: 4.39 and virtual site visit condition: 4.25), with Cohen's D = 0.143. Such high ratings could be justified by a wide range of communication affordances provided under both conditions (e.g., audio, chat, screen sharing). Other measures such as perceived affective understanding (baseline condition:4.08 and virtual site visit condition: 3.76, Cohen's D = 0.331), the perceived emotional interdependence (baseline condition: 3.64 and virtual site visit condition: 3.53, Cohen's D = 0.091), and the perceived behavior interdependence (baseline condition: 3.72 and virtual site visit condition: 3.42, a Cohen's D = 0.274) were comparable and rated relatively high. In all these affective, emotional, and behavioral measures, the baseline condition was rated slightly higher than the virtual site visit condition. A protentional approach that might enhance these measures in the virtual site visit condition is to enable users to their camera to have their real facial expression and gestures in addition to their virtual avatars to be used in such collaborative works or allow users to create personalized 3D avatars with realistic appearances. These can better represent their emotional, behavioral, and attitudinal states on the virtual site. Lastly, based on the combined responses for overall social presence, no significant difference was found between baseline condition (4.04) and virtual site visit condition (3.87), with a Cohen's D = 0.166. The Cohen's D showed a small effect of the sample size for the generalization of the results. Future research should collect more sample size to resolve this issue. Regarding PBL theory, various social cues (e.g., personalization, voice, image, and embodiment) within the collaborative problem-solving activity allowed students to interact with peers and contruct their mental model, which potentially resulted in motivationally and cognitively rich collaborative problem-solving site visits [27]. Moreover, synchronous and asynchronous collaborative affordances expose students to attain stronger and deeper learning experiences in such collaborative learning spaces. Even though results could not demonstrate virtual site visit presented a significantly higher overall social presence than the video-conferencing tool, the virtual site visit was still identified as having a high social presence.

Table 5
Results for social presence.

Parameters	Baseline Condition	Virtual Site Visit Condition	p-value	Cohen's D
Scale: Strongly Disagree (1)–(5) Strongly Agree	Mean (SD)	Mean (SD)		
Co-presence	4.11 (0.82)	4.28 (0.61)	0.333	0.235
Attentional Allocation	4.28 (0.78)	3.92 (0.91)	0.740	0.425
Perceived Message Understanding	4.39 (0.93)	4.25 (1.02)	0.550	0.143
Perceived Affective Understanding	4.08 (0.94)	3.76 (0.99)	0.221	0.331
Perceived Emotional Interdependence	3.64 (1.12)	3.53 (1.30)	0.699	0.091
Perceived Behavior Interdependence	3.72 (1.00)	3.42 (1.18)	0.241	0.274
Combined Responses for Overall Social Presence	4.04 (0.97)	3.87 (1.07)	0.101	0.166

5.4. Fatigue

Participants from both conditions reported a low level of fatigue in accomplishing the collaborative plan-reading task (See Table 6). However, participants reported a significantly higher level of general, visual, and social fatigues in the virtual site visit condition (2.26, 2.22, and 1.69 respectively) than the baseline condition (1.63, 1.74, 1.35 respectively), with Cohen's D = 0.613, 0.460, 0.487 respectively. In terms of motivational and emotional fatigues, although participants reported higher levels of fatigues in the virtual site visit condition (1.83 and 1.72 respectively) than the baseline condition (1.52 and 1.50 respectively),

Table 6
Results for fatigue questions.

Parameters	Baseline Condition	Virtual Site Visit Condition	p-value	Cohen's D
Scale: Not at all (1)–(5) Very much	Mean (SD)	Mean (SD)		
General Fatigue	1.63 (0.90)	2.26 (1.14)	0.002	0.613
Visual Fatigue	1.74 (0.91)	2.22 (1.16)	0.018	0.460
Social Fatigue	1.35 (0.55)	1.69 (0.82)	0.015	0.487
Motivational Fatigue	1.52 (0.77)	1.83 (1.00)	0.071	0.347
Emotional Fatigue	1.50 (0.93)	1.72 (0.98)	0.228	0.230
Combined Responses for Overall Fatigue	1.55 (0.83)	1.94 (1.05)	0.000	0.412

they were not significantly different, with Cohen's D = 0.347, 0.230 respectively. Based on the combined responses for overall fatigue, participarted in virtual site visit condition (1.94) reported significantly higher fatigue than participants in the baseline condition (1.55), with a Cohen's D = 0.412. Cohen's D indicated a middle effect of the sample size for the generalization of the results. A potential reason behind these higher fatigue ratings in the virtual site visit condition could be associated with the higher amount of time spent on completing the plan-reading task within the virtual site visit condition (16:26) than the baseline condition (21:05). The time duration effect on fatigue had been studied previously by [60], who suggested that people with longer online meeting durations tend to feel more fatigued than those with shorter online meeting durations. In addition, the need to go through additional steps in the virtual site visit condition to conduct the plan-reading task (e.g., navigating through the virtual environment to find the right rooms and associated floor plans), and using other interaction and exploration tools (e.g., arrow keys to explore the virtual environment and optical pointers to look around and point to objects) might have increased the level of fatigue. It should also be noted that all participants had previous experience using the Zoom® tool used in the baseline condition, while the majority had never used Mozilla Hubs before. This lack of familiarity and previous hands-on experience with Mozilla Hubs® might have also increased the level of fatigue in the virtual site visit condition. For example, one user participating in the virtual site visit condition indicated that: "*It is the first time to use Mozilla Hubs; it took a lot to figure it out*". Finally, the previously discussed technical difficulties encountered while using the virtual site visit (e.g., missing audio, missing features or objects on the sites) and not having access to a high bandwidth and low-latency network to load the virtual site visit on the browser might have also played some roles in increasing the level of fatigue in the virtual site visit condition. This has been evidenced by some users indicating some inconsistencies in the audio and others saying that: "*It takes a while to load into rooms and sometimes kicks me out.*", potentially delaying student–student collaboration and increasing the fatigue level. While these are some potential reasons, further research is required to understand the sources of different types of fatigue in virtual collaboration and communication settings.

5.5. System usability

Students from both baseline condition and virtual site visit condition indicated that they would like to use both systems frequently, with average ratings of 3.56 and 3.67 (Q1), with Cohen's D = 0.109 (See Table 7). They also found both systems (baseline condition: 3.83 and virtual site visit condition: 3.67, with Cohen's D = 0.175) to be relatively easy to use (Q3). The various function in both systems (baseline condition: 3.61 and virtual site visit condition: 3.78, with Cohen's D = 0.183) are well integrated (Q5) and considered that most people could learn how to use both systems (baseline condition: 3.56 and virtual site visit condition: 4.00, with Cohen's D = 0.499) very quickly (Q7). Participants also felt confident using both systems (baseline condition: 3.83 and virtual site visit condition: 3.50, with Cohen's D = 0.316) (Q9). Both systems (baseline condition: 2.17 and virtual site visit condition: 2.56, with Cohen's D = 0.355) were not found to be unnecessarily complex (Q2), and participants did not agree on the need for being supported by a technical person to be able to use both systems (baseline condition: 2.06 and virtual site visit condition: 2.78, with Cohen's D = 0.571) (Q4). In addition, they did not consider both systems to have too much inconsistency (baseline condition: 2.11 and virtual site visit condition: 2.72, with Cohen's D = 0.567) (Q6), to be awkward to use (baseline condition: 2.39 and virtual site visit condition: 2.83, with Cohen's d = 0.402) (Q8), or to require a lot of knowledge before they could be used (baseline condition: 2.22 and virtual site visit condition: 2.67, with Cohen's D = 0.420) (Q10). This study would use an overall usability scoring system [80] to further obtain valuable findings on the difference between both systems by integrating the ten items' results. The validation of the

Table 7
System Usability Scale (SUS) results.

Questions	Baseline Condition	Virtual Site Visit Condition	p-value	Cohen's D
Scale: Strongly Disagree (1)–(5) Strongly Agree	Mean (SD)	Mean (SD)		
Q1: I think that I would like to use this system frequently	3.56 (0.984)	3.67 (1.029)	0.669	0.109
Q2: I found the system unnecessarily complex.	2.17 (0.924)	2.56 (1.247)	0.340	0.355
Q3: I thought the system was easy to use.	3.83 (0.924)	3.67 (0.907)	0.551	0.175
Q4: I think that I would need the support of a technical person to be able to use this system.	2.06 (1.110)	2.78 (1.396)	0.104	0.571
Q5: I found that the various functions in the system were well integrated.	3.61 (0.850)	3.78 (1.003)	0.356	0.183
Q6: I thought there was too much inconsistency in this system.	2.11 (0.900)	2.72 (1.227)	0.101	0.567
Q7: I would imagine that most people would learn to use this system very quickly	3.56 (0.922)	4.00 (0.840)	0.095	0.499
Q8: I found the system very awkward to use.	2.39 (1.092)	2.83 (1.098)	0.206	0.402
Q9: I felt very confident using the system	3.83 (1.043)	3.50 (1.043)	0.305	0.316
Q10: I needed to learn a lot of things before I could get going with this system.	2.22 (1.215)	2.67 (0.907)	0.190	0.420
Overall Usability Score [80]:	68.60 (2.708)	62.65 (3.114)	0.07	2.039

overall usability scoring system was provided by [81], who used it to test the usability of a VR 3D model in improving users' design collaboration. In this study, the overall usability scores for baseline and virtual site visit conditions were closed to significant differences (p = 0.07), with 68.60 and 62.65, with Cohen's d = 2.039. Cohen's d indicated a large effect of the sample size for the generalization of the results. The adjective ratings of both platforms' usability were between "Good" and "OK", and the acceptability range was low marginal. Nevertheless, the scores of 62.65 for the virtual site visit condition is comparable with other studies exploring the effect of virtual collaborative environment in the education field [82]. According to the overall usability score difference between both systems, users in the baseline condition presented more confidence than users in the virtual site visit. For example, users in the baseline condition spent a shorter time completing the plan-reading activity and did not report technical issues during the experiment. Even so, the baseline condition could make minor improvement. For example, one user complained, "*frequently switching in and out of sharing screen was annoying.*" To resolve the design issue, designing a more appropriate workflow of plan-reading activity (i.e., reordering plan-reading questions to avoid repeated opening and closing the same drawings) would reduce the frequency of switching in and out of sharing screen and improve user experience. While users in virtual site visit conditions had to spend more time fixing technical difficulties (e.g., audio inconsistency, image distortion, blurriness, long waiting time to load into the room) due to the relatively complex system. For example, some users in the virtual site visit condition commented, "*My partner is in fly mode, but I could not figure out how to fly,*" "*I was confused at first to use it, and I might need a technical person.*" To resolve technical and design issues in the virtual site visit condition, it is necessary to provide clearer system instruction before the activity starts and require users to work in the system with stable bandwidth for a better user experience. Moreover, despite showing a slightly lower score of overall usability in the virtual site visit condition, students' feedback and study results acknowledged the potential of such online site visits to improve students' learning motivation. For example, prior to the start of the experiment, some students were looking for some classrooms where they physically attended lectures before COVID-19. Some users in the condition indicated that *"the system was fun to use"* and that *"it could help me actually see the building better"*.

6. Conclusion and future research

This research leveraged the use of virtual collaborative spaces for conducting online location-independent site visits to overcome challenges associated with existing learning and teaching methods on site visits where such contextualized learning field trips are dangerous, unsafe, or impossible to visit. For this purpose, an online site visit was developed, and a between-subject experiment involving a plan-reading activity was conducted to understand students' learning outcomes under such virtual site visits. Results showed that the virtual site visit could assist students in understanding plan-reading information but required a longer duration to complete the task. It was also found that virtual site visits could significantly improve users' sense of presence by exposing them to real-world spatiotemporal contexts of the site. It was also observed that students reported a high level of social presence while interacting with their partners on the virtual site visit. Students also presented slightly low fatigue in all types; however, their general, visual, and social fatigues were significantly higher than the baseline Zoom® condition. Finally, the overall usability scores showed low marginal acceptability, which illustrates a slightly unnecessarily complex system with some technical issues that might not make it easy to use.

The findings of this research point to the online site visit as an alternative to deliver collaboratively contextualized learning within the distance construction curriculum. The observed results within the online site visit indicated that students could interact with the virtual environment and obtain a strong sense of presence, which supported students' understanding of information interpretation in 2D and 3D. Meanwhile, students were able to collaborate within the shared virtual spatiotemporal contexts, which improved students' social presence and eliminated the restrictions of collaboration and communication in distance education. Additionally, the web-based virtual collaborative space was easily accessible online, allowing student access with any device. Moreover, the technical development process to create such an online site visit is not complex compared with traditional engines for developing a virtual environment. For example, Unity®, one of the popular traditional game engines to create digital spaces, has a complex user interface with a large number of tools and design features. This makes it difficult for beginners to learn to use these Unity tools needed to create a virtual environment in a short period of time. Besides, computer programming is a required skill to develop a digital space using Unity®. However, developing this virtual site visit proposed in this study is simple with a few necessary design tools. Besides, virtual site visits can be custom created using different 3D models (e.g., generated by Revit® or 3Ds Max®), and these models, together with other added information (e.g., video, audio, text), can be imported and integrated into Mozilla Spoke® and eventually published to Mozilla Hubs®. In addition, Mozilla Hubs® eliminates the need for computer programming and reduces the time investment for course instructors to develop the digital spaces. Overall, the study's findings contribute to improving the existing online site visit in AEC education by creating a clear workflow of design and implementation of online delivery of spatiotemporal contexts of sites and offering an effective device-agnostic alternative when these learning opportunities are not available. However, there were specific research and technological challenges in implementing such online visits in this study that should be noted.

In terms of research limitations, the plan-reading activity was limited to a group of 36 participants, limiting the generalization of the obtained plan-reading performance and user experience results. Because the research's goal was to replicate the site visit conducted in the targeted undergraduate course (i.e., BCN 3255 Graphic Communication in Construction), purposeful sampling in the class drove the total possible number of participants. Students' background (i.e., familiarity with plan reading, Mozilla Hubs, and educational background) was also tied to the class selection and sampling. As the class students were naturally at a similar level within the construction program and plan-reading learning was one of the core components in this class, the participants in the experiment had comparable backgrounds with low variability in their plan-reading knowledge base. Hence, our sampling strategy was a limitation of this research. Future research should be considered collecting a larger, more general group of students from different AEC backgrounds. Nonetheless, this experimental investigation offered insight into utilizing online site visits in construction education, and the sample size that seems comparable with the number of participants recruited in other studies exploring the effect of virtual collaborative environments in the education field [27,36]. Moreover, this study only applied a plan-reading activity to evaluate the learning outcome in the virtual site visit. Additional studies should also be conducted to understand virtual site visits' effects on other construction-related educational activities. Also, even though the collaborative plan-reading task design improved student–student interaction, this has not yet achieved the desired condition. For example, some students tended to focus on their drawings and corresponding questions rather than collaborating with their partners. More innovative collaborative task and space designs are required to motivate the students to further collaborate in such online site visits. In addition, the comparison of participants' performances across both conditions might have been impacted by the pre-experiment hands-on software experience. In fact, Mozilla Hubs® - as a new virtual collaborative platform – was unacquainted for most students, whereas Zoom® was the most common videoconferencing software adopted. Therefore, students might have had different starting points when it comes to using Mozilla Hubs® and Zoom®. Providing students hands-on experience with Mozilla Hubs® before the experiment might have offered the same starting point for both groups reducing unexpected influence during the experiment.

In terms of technological challenges, using online site visits to perform plan-reading tasks had some visual quality limitations. First, the blurriness of the building texture reduced the feeling of being on a real-world construction jobsite, which might have been caused by the material texture settings used when exporting the 3D model. Also, the limitations imposed by Mozilla Hubs® on the content size reduced the quality of the uploaded 2D drawings and images within the environment, which might have negatively affected students' plan-reading performance and fatigue levels. Applying real-world construction materials textures in the virtual spaces might improve usability outcomes of the virtual environment that should be further studied. Finally, the students reported technical challenges (e.g., audio inconsistencies, low-resolution visual contents, fluctuating bandwidth, internet connection issues) that might have ultimately led to longer activity completion duration and higher fatigue levels. Using students' computers and relying on their personal internet connections might have led to several of these technical difficulties. These challenges show the need for future research in laboratory-controlled settings to better explore the benefits of such online site visits.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgement

This material is based upon work supported by the National Science Foundation under Grant No. 1821852.

References

[1] M.B. McGrath, J.R. Brown, Visual learning for science and engineering, IEEE Comput. Graph. Appl. 25 (5) (2005) 56–63, https://doi.org/10.1109/MCG.2005.117.

[2] D.S. Anderson, J.L. Miskimins, Using field-camp experiences to develop a multidisciplinary foundation for petroleum engineering students, J. Geosci. Educ. 54 (2) (2006) 172–178, https://doi.org/10.5408/1089-9995-54.2.172.

[3] M. Rais-Rohani, K. Koenig, T. Hannigan, Keeping students engaged: an overview of three introductory courses in aerospace engineering, in: ASEE Annual Conference Proceedings, 2003, pp. 10093–10116. https://doi.org/10.18260/1-2–11862.

[4] S. Mizokami, Y. Kumagai, Reflections on the Fukushima Daiichi Nuclear Accident: Toward Social-Scientific Literacy and Engineering Resilience, 2015.

[5] T. Kuflik, A.J. Wecker, J. Lanir, O. Stock, An integrative framework for extending the boundaries of the museum visit experience: linking the pre, during and post visit phases, Inf. Technol. Tour. 15 (1) (2015) 17–47, https://doi.org/10.1007/s40558-014-0018-4.

[6] O.A. Adedokun, K. Hetzel, L.C. Parker, J. Loizzo, W.D. Burgess, J. Paul Robinson, Using virtual field trips to connect students with university scientists: core elements and evaluation of zipTripsTM, J. Sci. Educ. Technol. 21 (5) (2012) 607–618, https://doi.org/10.1007/s10956-011-9350-z.

[7] C. Zhang, Y. Lu, R. Xu, X. Ye, Y. Shi, P. Lu, An educational tool based on virtual construction site visit game, Mod. Appl. Sci. 11(8) (2017). https://doi.org/10.5539/mas.v11n8p47.

[8] G. Palaigeorgiou, G. Malandrakis, C. Tsolopani, Learning with drones: flying windows for classroom virtual field trips, in: Proceedings - IEEE 17th International Conference on Advanced Learning Technologies, ICALT (2017, Aug. 2017) 338–342. https://doi.org/10.1109/ICALT.2017.116.

[9] Denis McQuail, McQuail's Mass Communication, 2010.

[10] T.A.U. Anderson, Towards a Theory of Online Learning, 2004.

[11] J. Cain, A. Policastri, Using facebook as an informal learning environment, Am. J. Pharm. Educ. 75 (10) (2011) 1–8, https://doi.org/10.5688/AJPE7510207.

[12] P. Ashford, A. Mills, Evaluating the Effectiveness of Construction Site Visits as a Learning Experience for Undergraduate Students Enrolled in a Built Environment Course, 2006, Accessed: Oct. 06, 2021. [Online]. Available: http://hdl.handle.net/10536/DRO/DU:30037045.

[13] G. Arslan, Design of a web-based virtual construction site visit for education of civil engineering student (PartI), Towards Vis. Inform. Technol. Civ. Eng. (2004) 391–398, https://doi.org/10.1061/40704.

[14] M. Murray, S. Tennant, Off-piste pedagogy': construction site visits for undergraduate civil engineers, in: Sixth International Symposium of Engineering Educ, Jul (2016), pp. 165–172.

[15] R. Eiris Pereira, M. Gheisari, Site visit application in construction education: a descriptive study of faculty members, Int. J. Constr. Education and Research 15 (2) (2019) 83–99, https://doi.org/10.1080/15578771.2017.1375050.

[16] R. Eiris, M. Gheisari, Site visit application in construction education: a descriptive study of students' perspectives, in: 54th ASC Annual International Conference Proceedings, 2018, pp. 67–73.

[17] M.N.K. Boulos, A.D. Taylor, A. Breton, A synchronous communication experiment within an online distance learning program: a case study, Telemed. e-Health 11 (5) (2005) 583–593, https://doi.org/10.1089/tmj.2005.11.583.

[18] R. Moreno, R. Mayer, Interactive multimodal learning environments: special issue on interactive learning environments: contemporary issues and trends, Educ. Psychol. Rev. 19 (3) (2007) 309–326, https://doi.org/10.1007/s10648-007-9047-2.

[19] C.A. Jara, F.A. Candelas, F. Torres, C. Salzmann, D. Gillet, F. Esquembre, S. Dormido, Synchronous collaboration between auto-generated WebGL applications and 3D virtual laboratories created with Easy Java Simulations, IFAC Proc. 45 (11) (2012) 160–165, https://doi.org/10.3182/20120619-3-RU-2024.00039.

[20] E.B. Klemm, G. Tuthill, Virtual field trips: best practices, Int. J. Instr. Media 30 (2) (2003) 177–193.

[21] J. Wen, M. Gheisari, A review of virtual field trip applications in construction education, in: Construction Research Congress 2020: Safety, Workforce, and Education 2020, pp. 782–790. https://doi.org/10.1061/9780784482872.085.

[22] R.H. Crawford, A. Stephan, C. Landorf, G. Brewer, K. Maund, S. Ward. Onsite and Online: A 4-dimensional Multi-disciplinary Learning Environment for Construction Industry Professionals, Architectural Science Association, 2015, pp. 987–996.

[23] E. Jaselskis, J. Ruwanpura, T. Becker, L. Silva, P. Jewell, E. Floyd, Innovation in construction engineering education using two applications of internet-based information technology to provide real-time project observations, J. Constr. Eng. Manag. 137 (10) (2010) 829–835, https://doi.org/10.1061/(ASCE)CO.1943-7862.0000297.

[24] V.R. Kandi, F. Castronovo, P. Brittle, S. Mastrolembo Ventura, D. Nikolic, Assessing the impact of a construction virtual reality game on design review skills of construction students, J. Archit. Eng. 26(4) 04020035, 2020. https://doi.org/10.1061/(asce)ae.1943-5568.0000434.

[25] R. Eiris, J. Wen, M. Gheisari, iVisit-collaborate: collaborative problem-solving in multiuser 360-degree panoramic site visits, Comput. Educ. 177 (2022) 104365, https://doi.org/10.1016/j.compedu.2021.104365.

[26] R. Eiris, J. Wen, M. Gheisari, iVisit: digital interactive construction site visits using 360-degree panoramas and virtual humans, in: Construction Research Congress 2020: Computer Applications, ASCE, 2020, pp. 1106–1116, https://doi.org/10.1061/9780784482865.117.

[27] Q.T. Le, A. Pedro, C.S. Park, A social virtual reality based construction safety education system for experiential learning, J. Intell. Robot. Syst. Theory Appl. 79 (3–4) (2015) 487–506, https://doi.org/10.1007/s10846-014-0112-z.

[28] Q.T. Le, C.S. Park, Construction safety education model based on second life, in: Proceedings of IEEE International Conference on Teaching, Assessment, and Learning for Engineering, TALE 2012, 2012. https://doi.org/10.1109/TALE.2012.6360336.

[29] "Second life." https://secondlife.com/ (accessed Jul. 01, 2021).

[30] K. Ku, P.S. Mahabaleshwarkar, Building interactive modeling for construction education in virtual worlds, Electron. J. Inf. Technol. Constr. 16 (2011) 189–208.

[31] S. Van Nederveen, Collaborative design in second life, in: 2nd Int. Conf. World Constr. Proj. Manag., 2007, Accessed: Oct. 06, 2021. [Online]. Available: https://research.tudelft.nl/en/publications/collaborative-design-in-second-life.

[32] A. Anderson, C.S. Dossick, Avatar-model interaction in virtual worlds improves distributed team collaboration through issue discovery, in: Proceedings of the 2014 International Conference on Computing in Civil and Building Engineering, 2014, pp. 793–800. https://doi.org/10.1061/9780784413616.099.

[33] "Unity Real-Time Development Platform | 3D, 2D VR & AR Engine." https://unity.com/ (accessed Oct. 06, 2021).

[34] J. Du, Y. Shi, Z. Zou, D. Zhao, CoVR: cloud-based multiuser virtual reality headset system for project communication of remote users, J. Constr. Eng. Manag. 144 (2) (2018) 04017109, https://doi.org/10.1061/(asce)co.1943-7862.0001426.

[35] S. Mahmood, Instructional strategies for online teaching in COVID-19 pandemic, Hum. Behav. Emerg. Technol. 3 (1) (2021) 199–203, https://doi.org/10.1002/HBE2.218.

[36] A. Yoshimura, C.W. Borst, Remote Instruction in Virtual Reality: A Study of Students Attending Class Remotely from Home with VR Headsets, 2020. https://doi.org/10.18420/muc2020-ws122-355.

[37] J. Roschelle, S.D. Teasley, The construction of shared knowledge in collaborative problem solving, Comput. Support. Collab. Learn. (1995) 69–97, https://doi.org/10.1007/978-3-642-85098-1_5.

[38] P. Dillenbourg, Introduction: what do you mean by 'collaborative learning'?, in: Collaborative lea, Cognitive and computational approaches, 1999, pp. 1–19.

[39] L. Smith, J.T. Macgregor, What is collaborative learning? Assessment 117 (5) (1992) 10–30.

[40] D.E. Graaff, K. Anette, Characteristics of problem-based learning, Int. J. Eng. Educ. 19 (5) (2003) 657–662.

[41] K.R. Butcher, The multimedia principle, Cambridge Handb. Multimed. Learn. Second Ed., 2014, pp. 174–205. https://doi.org/10.1017/CBO9781139547369.010.

[42] E.H.J. Yew, K. Goh, Problem-based learning: an overview of its process and impact on learning, Heal. Prof. Educ. 2 (2) (2016) 75–79, https://doi.org/10.1016/J.HPE.2016.01.004.

[43] J.R. Anderson, Problem solving and learning, Am. Psychol. 48 (1) (1993) 35–44, https://doi.org/10.1037/0003-066X.48.1.35.

[44] R. Eiris, J. Wen, M. Gheisari, iVisit – practicing problem-solving in 360-degree panoramic site visits led by virtual humans, Autom. Constr. 128 (2021) 103754, https://doi.org/10.1016/j.autcon.2021.103754.

[45] M.G. Moore, Editorial, what does research say about the learners using computer-mediated communication in distance learning? Am. J. Distance Edu. 16 (2) (2002) 61–64.

[46] T. Schellens, M. Valcke, Fostering knowledge construction in university students through asynchronous discussion groups, Comput. Educ. 46 (4) (May 2006) 349–370, https://doi.org/10.1016/J.COMPEDU.2004.07.010.

[47] J.H. Flavell, Metacognitive aspects of problem solving, Nat. Intell., 1976, Accessed: Oct. 06, 2021. [Online]. Available: https://ci.nii.ac.jp/naid/10021876052.

[48] R.E. Mayer, Principles based on social cues in multimedia learning: Personalization, voice, image, and embodiment principles, in: R.E. Mayer (Ed.), The Cambridge Handbook of Multimedia Learning, Second Edition, Cambridge University Press, 2014, pp. 345–368.

[49] R.C. Clark, R.E. Mayer. E-learning and the Science of Instruction: Proven Guidelines for Consumers and Designers of Multimedia Learning, John Wiley Sons, 2016.

[50] M. Frank, R. Fruchter, M. Leinikka, A. Member, Global teamwork: components of engaging and productive meetings, in: ICCBE-XVI:, Int. Conf. on Computing in Civil and Building Engineering, 2016, pp. 1933–1940.

[51] R. Fruchter, M3R: transformative impacts of mixed media mixed reality collaborative environment in support of AEC Global Teamwork, in: I. Mutis, R. Fruchter, C.C. Menassa (Eds.), Transforming Engineering Education: Innovative Computer-Mediated Learning Technologies, American Society of Civil Engineers, Reston, VA, 2018, pp. 229–257, https://doi.org/10.1061/9780784414866.ch08.

[52] R.E. Slavin, Instruction based on Cooperative Learning, Handbook of Research on Learning and Instruction, 2011. https://doi.org/10.4324/9780203839089-26.

[53] J. Sweany, P. Goodrum, J. Miller, Analysis of empirical data on the effects of the format of engineering deliverables on craft performance, Autom. Constr. 69 (2016) 59–67, https://doi.org/10.1016/J.AUTCON.2016.05.017.

[54] M. Foroughi Sabzevar, M. Gheisari, L.J. Lo, Improving access to design information of paper-based floor plans using augmented reality, Int. J. Constr. Educ. Res. 17 (2) (2021) 178–198, https://doi.org/10.1080/15578771.2020.1717682.

[55] S. Azhar, J. Kim, A. Salman, Implementing virtual reality and mixed reality technologies in construction education: students' perceptions and lessons learned, ICERI2018 Proc. 1 (December) (2018) 3720–3730, https://doi.org/10.21125/iceri.2018.0183.

[56] Y.-C. Chen, H.-L. Chi, W.-H. Hung, S.-C. Kang, Use of tangible and augmented reality models in engineering graphics courses, J. Prof. Issues Eng. Educ. Pract. 137 (4) (2011) 267–276, https://doi.org/10.1061/(ASCE)EI.1943-5541.0000078.

[57] R. Eiris, Y. Sun, M. Gheisari, B. Marsh, P. Lautala, VR-OnSite – Online Site Visits using web-based Virtual Environments, in: Construction Research Congress 2022, 2022, pp. 100–109.
[58] E. Chen, K. Kaczmarek, H. Ohyama, Student perceptions of distance learning strategies during COVID-19, J. Dent. Educ. 85 (S1) (2021) 1190–1191.
[59] J. Wen, M. Gheisari, S. Jain, Y. Zhang, R.E. Minchin, Using cloud-based augmented reality to 3D-enable the 2D drawings of AISC steel sculpture: a plan-reading educational experiment, J. Civ. Eng. Educ. 147 (3) (2021) 04021006, https://doi.org/10.1061/(ASCE)EI.2643-9115.0000046.
[60] J.N. Bailenson, Nonverbal overload: a theoretical argument for the causes of Zoom fatigue, Technol. Mind Behav. 2(1) (2021). https://doi.org/10.1037/tmb0000030.
[61] "Hubs by Mozilla," 2021. https://hubs.mozilla.com/ (accessed Jul. 01, 2021).
[62] Y. Sun, M. Gheisari, Potentials of virtual social spaces for construction education, in: EPiC Series in, Environment 2 (2021) 469–459. https://doi.org/10.29007/sdsj.
[63] "Spoke by Mozilla," 2021. https://hubs.mozilla.com/spoke (accessed Oct. 11, 2021).
[64] R. Long, B. Peiris, Introducing Spoke: Make Your Own Custom 3D Social Scenes, Oct. 18, 2018. https://blog.mozvr.com/introducing-spoke/ (accessed Jul. 01, 2021).
[65] "Revit Software | Get Prices & Buy Official Revit 2022 | Autodesk," 2021. https://www.autodesk.com/products/revit/overview?term=1-YEAR&tab=subscription (accessed Oct. 11, 2021).
[66] "Simlab Soft - Enabling Interactive VR," 2021. https://www.simlab-soft.com/ (accessed Jul. 01, 2021).
[67] M. Slater, M. Usoh, A. Steed, Depth of presence in virtual environments, Presence Teleoperat. Virtual Environ. 3 (2) (1994) 130–144, https://doi.org/10.1162/pres.1994.3.2.130.
[68] S.T. Bulu, Place presence, social presence, co-presence, and satisfaction in virtual worlds, Comput. Educ. 58 (1) (2012) 154–161, https://doi.org/10.1016/j.compedu.2011.08.024.
[69] G. Fauville, M. Luo, A.C.M. Queiroz, J.N. Bailenson, J. Hancock, Zoom exhaustion & fatigue scale, SSRN Electron. J. (2021), https://doi.org/10.2139/ssrn.3786329.
[70] J. Brooke, SUS-A Quick and Dirty Usability Scale, 1996.
[71] B.G. Witmer, M.J. Singer, Measuring Presence in Virtual Environments, 1994.
[72] M. Usoh, E. Catena, S. Arman, M. Slater, Using Presence Questionnaires in Reality, 2000.
[73] S.E. Kober, C. Neuper, Personality and presence in virtual reality: does their relationship depend on the used presence measure? Int. J. Hum. Comput. Interact. 29 (1) (2013) 13–25, https://doi.org/10.1080/10447318.2012.668131.
[74] E. Pedroli, L. Greci, D. Colombo, S. Serino, P. Cipresso, S. Arlati, M. Mondellini, L. Boilini, V. Giussani, K. Goulene, M. Agostoni, M. Sacco, M. Stramba-Badiale, G. Riva, A. Gaggioli, Characteristics, usability, and users experience of a system combining cognitive and physical therapy in a virtual environment: positive bike, Sensors (Switzerland) 18 (7) (2018) 2343, https://doi.org/10.3390/s18072343.
[75] J. Wen, M. Gheisari, VR-Electricians: Immersive storytelling for attracting students to the electrical construction industry, Adv. Eng. Inf. 50 (2021) 101411, https://doi.org/10.1016/j.aei.2021.101411.
[76] A. Revythi, N. Tselios, Extension of technology acceptance model by using system usability scale to assess behavioral intention to use e-learning, Educ. Inf. Technol. 24 (4) (2019) 2341–2355, https://doi.org/10.1007/s10639-019-09869-4.
[77] H.B. Mann, D.R. Whitney, On a test of whether one of two random variables is stochastically larger than the other, Ann. Math. Stat. 18 (1) (1947) 50–60.
[78] S.S. Shapiro, M.B. Wilk, An analysis of variance test for normality (complete samples), Biometrika 52 (3–4) (1965) 591–611, https://doi.org/10.2307/2333709.
[79] N. Pellas, I. Kazanidis, N. Konstantinou, G. Georgiou, Exploring the educational potential of three-dimensional multi-user virtual worlds for STEM education: a mixed-method systematic literature review, Educ. Inf. Technol. 22 (5) (2017) 2235–2279, https://doi.org/10.1007/s10639-016-9537-2.
[80] A. Bangor, P. Kortum, J. Miller, Determining what individual SUS scores mean: adding an adjective rating scale, J. Usability Stud. 4 (3) (2009) 114–123.
[81] H. Huang, C. Lin, D. Cai, Enhancing the learning effect of virtual reality 3D modeling: a new model of learner's design collaboration and a comparison of its field system usability, Univ. Access Inf. Soc. 20 (3) (2021) 429–440.
[82] A. Granić, J. Nakić, M. Ćukušić, Preliminary evaluation of a 3D serious game in the context of entrepreneurship education, in: Central European Conference on Information and Intelligent Systems, 2017, pp. 91–98, Accessed: Aug. 16, 2021. [Online]. Available: http://projectsymphony.eu.