Assessment of Holographic Environment for Learning Sensing Technologies in CEM Education

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ABSTRACT

Despite the benefits and suitability of mixed reality as a learning tool for spatial and haptic delivery of educational content, the adaptability of mixed reality for teaching sensing technologies in construction education remains ambiguous. Sensing technologies have potentials to advance construction performance as highlighted by several studies and construction industry reports. To equip future workforce with the required skills, it is important they experientially deploying these technologies on the jobsite. However, institutions are experiencing different constraints such as weather, schedule, and COVID-19 restrictions to provide future workforce with required hands-on learning. The study argues the pedagogical value of a mixed reality learning environment for teaching sensing technologies through a usability study with construction engineering and management students who are familiar with sensing technologies. The study employed quantitative and subjective users' evaluation through a cognitive walkthrough of the learning environment using a mixed reality head-mounted display. Subjective data were obtained using think-aloud protocol and questionnaires on users' experience. Eye tracking device inbuilt in the mixed reality head-mounted display was employed to monitor the eye gaze movements and provide quantitative data of users' cognitive workload. Results from eye tracking, think-aloud protocol and questionnaires were triangulated to validate findings from the study. The study reveals the ease of use and effectiveness of the environment for learning sensing technologies. The characteristics, benefits, and deficiencies of the learning environment as a pedagogical tool in construction education are further highlighted.

INTRODUCTION

A survey conducted by Ogunseiju et al. (2020) identified a wide adoption of image-based sensing technologies such as laser scanners, drones, and cameras in the construction industry, with laser scanners being one of the most adopted sensing technologies. Deployment of laser scanners on construction projects often involves several skills such as decision-making skills and operational skills (i.e., hands-on skills required to implement laser scans). For example, Shanbari et al. (2016) asserts that technical principles and scan settings are the first step to learning laser scanning. The authors described other decision-making skills as selection of scan location, and considerations of the effect of weather and object occlusion on laser scanning. To acquire these skills, it is imperative that students experientially try-out and learn the operation of laser scanners for mitigating risks on construction projects. However, several challenges such as weather and schedule constraints exist to accessing the jobsite for experiential learning. Similarly, the effects of COVID-19 on experiential learning cannot be overemphasized, as the unprecedented restrictions to movement have made jobsite visits even more challenging. An alternative environment, analogous to a construction site, where students can interact with sensing technologies and learn their workings is therefore needed. To address this challenge, the authors recently developed a holographic environment where students can learn how to deploy sensing technologies on construction projects (Ogunseiju et al. 2020). As popularized by Microsoft, holographic environment also refers to augmented 3D objects in a mixed reality (MR) environment. Within the MR environment, students can, through manipulation, develop skills for identifying and addressing risks on construction projects using sensing technologies such as laser scanners.

To understand the effectiveness of the MR environment, it is imperative to identify benefits and challenges with the usability of the learning environment. Therefore, this study presents a usability evaluation of a MR environment for learning laser scanning in construction engineering and management (CEM) programs. The study adopts a qualitative assessment such as think-aloud protocol and quantitative evaluations from eye tracking data. Lastly, the study employs structured questionnaire for procuring data on demographics and usability of the learning environment.

BACKGROUND

Mixed Reality in construction education. These unprecedented times of global health crises have unveiled a paradigm shift in higher education and most educational institutions have started exploring remote and virtual learning environments for replacing or supplementing in-person learning. Higher institutions are rapidly embracing these learning environments to further upgrade the quality and delivery of educational contents (Ali 2020). Virtual learning environments are characterized by multi-media objects designed to provide immersive and interactive learning for students in different forms of reality such as augmented reality (AR), virtual reality (VR), and MR (Winn 1999). While VR presents a completely immersive environment where users are unaware of the real world, MR provides an environment where virtual objects are augmented into the real world or real-world objects are incorporated into a virtual environment (Pan et al. 2006). Extant studies have investigated the efficacy of MR in construction education. For example, Azhar et al. (2018) employed MR for simulating construction activities for educating students on jobsite safety, site planning, and logistics. Similarly, a recent study by Vasilevski and Birt (2020) revealed the effectiveness of MR, mobile visualization and BIM for enhanced spatial information delivery. The authors asserted that the developed environment stimulated a unique learning experience with enhanced learning, engagement, and motivation.

Sensing technologies in construction education. Despite the rise in the adoption of sensing technologies in the construction industry, a few studies have explored the incorporation of sensing technologies in construction education. Hurlebaus et al. (2012) presented a case study of sensing technologies in engineering education in Texas A&M University. Shanbari et al. (2016) presented how laser scanning was incorporated in a Building Information Modelling course. The authors showcased how students experienced hands-on learning of sensing technology, and how the course enhanced learning of building envelopes and features of laser scanning technology. However, the paucity of literature reveals a need for construction education to embrace sensing technologies in their curriculum, and further necessitates alternative learning environments for teaching sensing technologies.

Eye tracking for assessments in virtual learning environments. Several attempts have been made to evaluate the effectiveness and didactic value of virtual learning environments through usability questionnaires. While these techniques have been proven to be effective, the incorporation of eye tracking data, can provide ways for effective evaluation of learning and performance in virtual learning environment. Conati and Merten (2007) explained that users' perceptions and attention in reality can differ from digital learning environments, and eye tracking can be employed as an accurate measure of attention. For example, Wang et al. (2018) employed eye tracking data for assessing and comparing cognitive process of steel installation in a text-graph, AR-based and physical-model based learning environments. Pachman et al. (2016) employed eye tracking and self-rating techniques for identifying confusions in a virtual learning environment. The authors were able to associate fixations on irrelevant areas of the learning environment with self-reported confusion ratings.

MIXED REALITY SENSING TECHNOLOGY LEARNING ENVIRONMENT: AN EXAMPLE OF LASER SCANNING

The development of the MR learning environment was guided by the Learning-for-Use theoretical framework which allows students to construct their understanding through hands-on interaction with sensing technologies. Within the learning environment, students have access to scenes where they can explore construction sites, observe the workings of different sensors, and implement the sensing technologies. The laser scanner was modeled after two commercially available laser scanners: Faro Focus M70 and Trimble X8. To scan a stockpile within the MR environment, a menu interface of the laser scanner will be displayed to inform students of the key components and tasks required for operating a laser scanner (Figure 1a). The components include the tripod, scanner, and targets. To commence scanning, students select, position and level the tripod stands as shown in Figure 1a. Next, students can select and mount scanners on tripod stands. Then, the targets become accessible, and students can select and move targets to the desired location (Figure 1b). Students can select the scanner interface menu which consists of the scan settings such as resolution, quality, coverage, color, and profile (Figure 1c). Students will be required to interact with all the scan settings before the scan button can be activated. On selecting the coverage of the scan, 'red beams' from the laser scanner will be displayed to illustrate the selected scan coverage (Figure 1d). After all scan settings have been selected, students can activate the scanner to commence scanning. The scan will be displayed as images, and students will be prompted to save the scan images.

RESEARCH METHODOLOGY

To assess the usability of the learning environment, objective and subjective data were procured and analyzed following the methodology outlined in Figure 2. Objective data were obtained via eye tracking, while subjective data were procured through usability questionnaire and think-aloud protocol. The think-aloud protocol comprised recorded comments of participants and responses to guiding questions during the experiment.

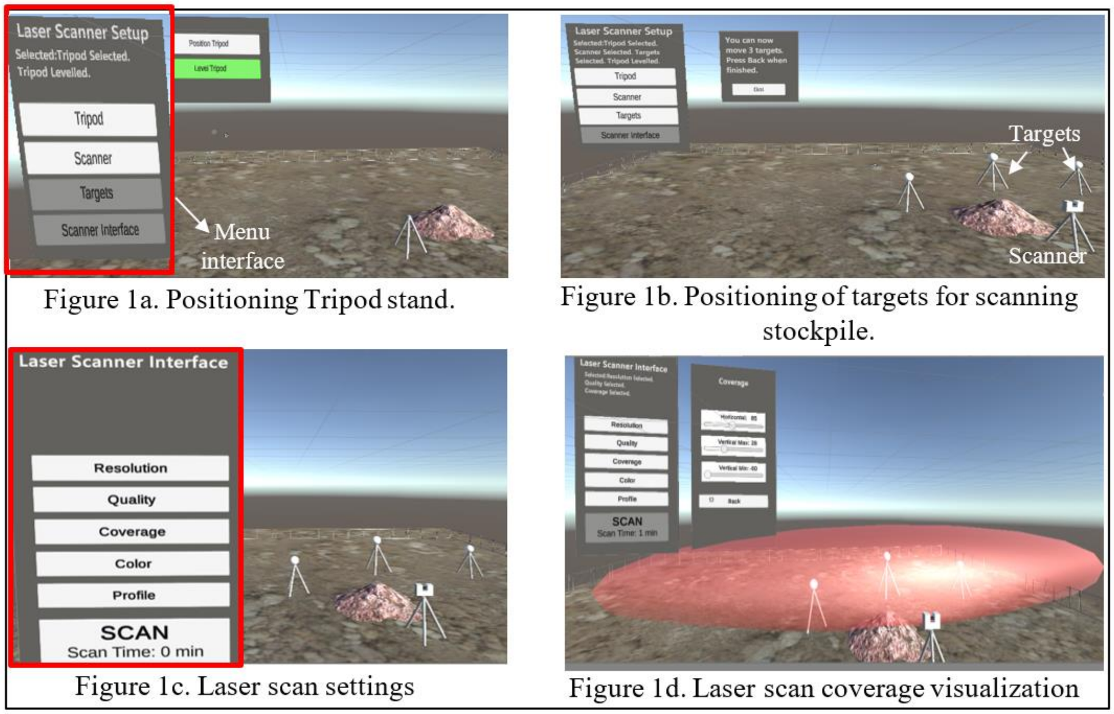

Figure 1a. Positioning Tripod stand.

Figure 1b. Positioning of targets for scanning stockpile.

Figure 1c. Laser scan settings

Figure 1d. Laser scan coverage visualization

Figure 1. Procedural guide to laser scanning.

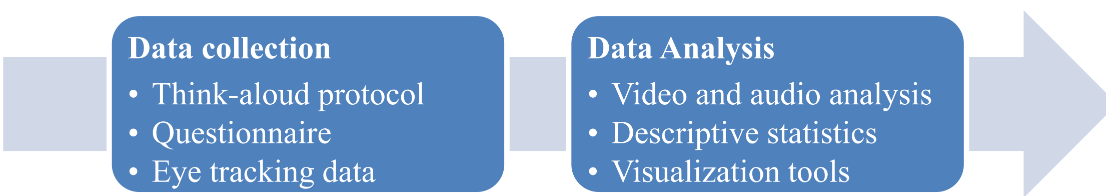

Figure 2. Methodology.

Device. The participants viewed the learning environment and interacted with the construction site and sensing technologies using HoloLens 2, a MR head-mounted display (HMD). The HMD provides a diagonal field of view of 52degrees, with a resolution of 47pixels per degree. The display from the HMD refreshes 240 times per second, resulting in a user experience of 60 frames per second. The HMD has an eye tracking feature. This was harnessed to further enrich the data collection for the usability study. This provides gaze origin, direction, and gaze time at approximately 30 frames per second (30Hz).

Usability questionnaire. Questionnaire was employed to procure data on the demographics and usability of the learning environment. While demographics included participants' age, level of experience with MR or VR, and sensing technologies, the usability questions procured information on the ease-of-use of the laser scanner components and user interface. The usability questions were designed on a 5-point Likert scale where 1 represents strongly disagree and 5 represents strongly agree.

Think-aloud protocol guide. To guide the experimental tasks and procure information on the ease of use and the learning contents of the learning environment, a think-aloud protocol guide was developed. This entails questions on the benefits and challenges of the learning environment. Participants were asked questions regarding how well their learning of sensing technologies was improved, features that improved their learning experience, and challenges they had with the interface of the environment. Participants were also probed on the features that best enhanced their understanding of laser scanning in the learning environment.

Study group. The study recruited a total of twelve participants who are students of Virginia Tech. Participants from the study were students from building construction, construction engineering and management, and civil engineering departments.

Experimental setup. Owning to the pandemic, participants were required to complete COVID, and study-specific consent forms as stipulated by the Institutional Review Board of Virginia Tech. Before actual experiments, participants were introduced to the workings of the MR HMD, the learning environment, and experimental tasks. Participants were then required to complete the demographics questions of the usability questionnaire. To ensure accurate eye tracking data, each participant' eye gaze was calibrated. Afterwards, participants completed laser scanning activities as depicted in Figure 1. Throughout the study, think-aloud protocol was employed to procure immediate feedback on the benefits and challenges of the environment. MR capture and audio recordings of performed tasks were simultaneously obtained, and after task completion, usability questions were completed.

Data analysis. To extract the benefits and challenges of participants with the learning environment from the think-aloud protocol, recorded videos of each participant were analyzed and transcribed (see Figure 2). For each question, similar themes were searched out within the transcript to further categorize and describe the data. Demographics and usability questions were analyzed using descriptive statistics such as mean and standard deviation. Lastly, the eye gaze data were visualized as heatmaps on the learning environment to procure information on distribution of visual attention and eye movement intensities.

RESULTS AND DISSCUSSION

Demographics. Participants of this study were ten males and two females, aged 23-45years with mean and standard deviation (SD) of 29 years (±6). Of the twelve participants, two participants had never used virtual or mixed reality devices, seven participants had used the devices once or twice, and three participants use the devices regularly. Regarding familiarity with sensing technologies, nine of the participants reported that they had previously interacted or worked with sensing technologies, and three participants have never interacted with sensing technologies.

Think-aloud. The think-aloud session was used to procure information on the benefit and challenges of the learning environment.

Benefits of the learning environment for laser scanning. During the experimental tasks, participants were asked if the learning environment improved their understanding of laser scanning. All the participants agreed that the environment enhanced their learning of laser scanning. Participant 8 stated that *'for me, it is a good teaching material for helping us to learn how to operate a laser scanner. Yeah. So, you have like the basic process or basic steps when you try to operate it. So, yeah, I think it is a good teaching material'.* Participant 2 stated that '*It improved my understanding of the pieces of laser scanning'.* Participant 3 explained that '*I think it is a pretty straightforward project, and generally easy to understand. I think the general process is pretty well designed'.* Participants were further probed on the feature that enhanced their understanding of laser scanning. Participant 9 stated that '*Actually, I could set it up* *anywhere and use the laser scanner. It was helpful for me to see the site through lasers'*. Participant 10 stated that '*Everything was well visualized, especially of the coverage part'*. According to participant 12, the procedural method helped to scaffold the learning of laser scanning. *The participant explained that 'The main feature that enhanced learning was the actual operations of the laser scanning, resolution, and all. That taught me how to use the device. Another thing is, it taught me the procedure format, like, step one is this, step two is this...'* The participant further explained how the learning environment guided the understanding of laser scanning. For example, the participant explaining the process of knowledge construction commented that *'tripod is required, place the tripod, levelling, place the scanner, the sequencing is really helpful to understand how, and what I should be doing if I am somebody who is new to laser scanners'.*

Challenges of the learning environment for laser scanning. Participants were asked what challenges were encountered with the learning interface such as menu panels, and interaction with the laser scanner components. Ten of the participants affirmed that they could easily move the tripod stand and targets to desired location. However, Participant 9 explained that it was difficult to pick up the laser scanner, although this participant has experience with VR or MR environment. Another challenge relates to the understanding of the target placements. A participant explained that '*If you are using this for someone who has never used the scanner before, placing the targets might be difficult to understand, but if you have used the scanner before, it is pretty straight forward'*. Lastly, regarding suggestions for improving their learning experience. Some participants stated that they felt the scanner interface menu needed more information. As explained by participant 7, '*putting the target, I need to have more details, how to put the target, how does it work, and the coverage and profile need more details or description. The resolution and color are easy'.* Similarly, participant 12 explained that to enhance the understanding and importance of the target for laser scanning, the laser scanner should be enhanced to detect and notify users of the visibility of the positioned targets. This will enhance the understanding and consequences of the laser scanner location.

Usability Questionnaire. When participants were asked if it was easy to move the laser scanner and targets to desired location, participants moderately agreed with a mean and (SD) rating of 3.83 (±6). The participants were asked if the buttons on the laser scanner interface are understandable, and they moderately agreed 4.42 (±0.7). When asked if the buttons on the laser scanner interface are easy to control, the participants moderately agreed 4.33 (±0.8). It can be inferred that the participants could easily interact with the laser scanner components, and laser scanner interface, which further informs the ease of use and comprehensibility of the laser scanner interface.

Eye tracking data. The eye tracking data were visualized as heatmaps on the learning environment. This revealed participants; eye movement intensities, and visual attention which further expounds on the comments from the think-aloud protocol. The heatmap reveals the high visual attention on the laser scanner menu panel and learning interfaces for all participants and suggests the informativeness of the learning interface. While most of the participants spent some time interacting with the laser scanner components such as targets and tripod stand, Participants 1, 3, 7 and 12 were revealed to have lesser attention and interaction with the laser scanner components and selected for representation (see Figure 3). This can be related to their experience with VR or MR, and laser scanners. For example, while Participants 1, 3, and 12 have previously used VR or MR, and have interacted with physical laser scanners, participant 7 uses VR or MR regularly, but inexperienced with laser scanners.

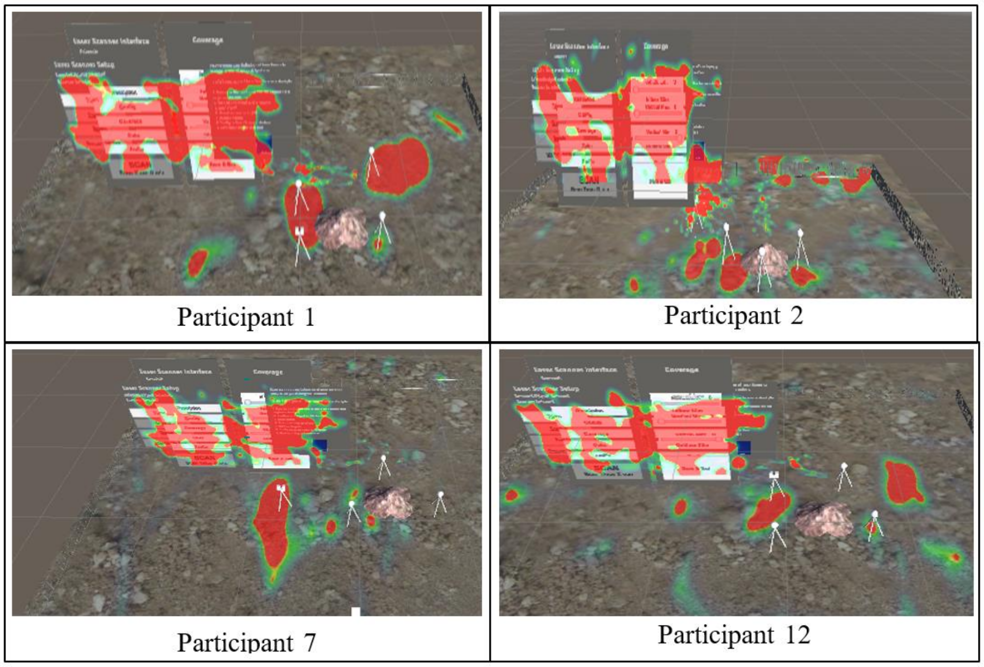

Figure 3. Heatmap data of laser scanning activities.

CONCLUSION AND FUTURE WORK

This study presents a usability assessment of a MR learning environment for equipping students with competencies for implementing laser scanning on construction projects. By triangulating the findings from the think aloud protocol, usability questionnaire, and heatmaps, the study elucidates students' benefits and challenges with interacting with laser scanners in the MR learning environment. Since the participants agreed that the interface was easy to use, and laser scanner components were easy to control, it may be inferred that high visual attention on the laser scanner interface was due to its high cognitive load. The revealed understandability of the laser scanner interface can be related to the procedural technique adopted for scaffolding users' learning experience which was stated as an important feature that enhanced the learning experience. Although demographics revealed that previous experience of VR or MR can influence attentiveness in a learning environment, other factors such as task completion time may be required to further validate this. Hence, with the demonstrated case study of scanning a stockpile, the findings from the study reveals the potentials of the learning environment for equipping students with technical skills for operating laser scanners.

As this is an ongoing study, the size of the participants can be stated as a limitation to the generalizability of the findings from the study. Hence, future work will focus on recruiting more participants with diverse experience with sensing technologies. In addition, future work will assess the impact of the learning environment as a pedagogical tool in CEM programs.

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