33 Development and Usability Testing of a Panoramic Augmented Reality Environment for Fall Hazard Safety Training

R. Eiris Pereira, H. F. Moore, M. Gheisari, and B. Esmaeili

Abstract

Construction is one of the leading industries in terms of workplace accidents. Safety training provides workers and professionals with tools to actively prevent these accidents. However, previous research has highlighted deficiencies in current safety training methods. Virtual Reality (VR) and Augmented Reality (AR) technologies have been employed to address some of the limitations associated with traditional training methods. While these technologies enable users to safely experience the complex nature of construction sites, they deliver unrealistic computer-generated simulations of the environment. Panoramic augmented reality presents a novel alternative that addresses some of the challenges present in VR and AR techniques in visualizing safety-related information in real construction sites. A pilot study was conducted to assesses the use of this technology as a safety training method for fall hazards. This study describes the development of the prototype training platform, the generation of training materials, and the findings of usability testing performed with university students. The results indicated that the technology was viewed favorably by participants, as the augmentations provided a simple and easy method to learn fall hazard-related information. Using the platform, participants an average 52% of the hazards presented. Participants also indicated that several aspects of the platform required improvement such as image quality, safety information displayed, and user interface interactions.

Keywords

Panoramic augmented reality • Fall hazards training • Usability testing

33.1 Introduction

Safety training is essential to enable workers and professionals to actively prevent accidents on the jobsite. Previous research has investigated the importance of safety training in the construction industry [1]. Despite finding that safety training has a critical influence on accident prevention, studies indicate a multitude of deficiencies in traditional safety training programs. For example, Wilkins [2] found both dissatisfaction with and ineffectiveness of OSHA's 10-h construction safety training course. Survey results revealed that less than half of respondents (49%) either "agreed" or "strongly agreed" that they

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understood the material covered. Zuluaga et al. [3] conducted interviews at 49 construction projects, and most respondents (57.1%) described the safety training they received as "low engaging."

In response to these shortcomings, academia has explored the used of virtual reality (VR) and augmented reality (AR) to train construction workers and professionals on virtual jobsites. Nevertheless, despite the immersive potential of VR and AR to generate unlimited training scenarios, these virtual environments are uncapable of simulating real working conditions. Wang and Dunston [4] argued that VR provides a limited degree of realism, potentially leading to trainees who have adequate training in virtual environments, but who cannot perform with the same proficiency in real world operations. Further, VR requires high computational costs and time-consuming modelling tasks [5]. After such an investment, the VR environment may be applicable to only one specific project or useful to only certain members of the construction industry [6]. AR presents a different set of issues that hinder its potential as a training method. It is limited to both the spatiotemporal context and geolocation of the trainee [7]. Moreover, AR also introduces the problem of "drift." A sudden movement may cause the digital object to drift away from its designated position and create a disconnect between the real world and virtual augmentation [7].

Using 360° panoramic augmented reality proposes an alternative to the traditional VR and AR limitations. Within the mixed reality continuum [8], 360° panoramas are considered in the literature to be virtual reality [9] or mixed reality [10] due the intrinsic properties of this method, in which true reality is captured with a complete view of the user's surroundings, creating a naturally immersive environment [11]. 360° panoramic augmented reality addresses the need for computationally intensive graphical renderings, which can never fully mimic true reality, while simultaneously mitigating the need for a user to be in any specific geographical location. By using this novel method, a trainee can have a true-to-life experience of a dynamic construction jobsite, without any safety or spatiotemporal constraints. This research discusses the development process and usability testing of a safety training platform for selected fall hazards based on 360° panoramic augmented reality.

33.2 Methodology

The platform developed in this study employs 360° panoramic images with augmented safety data to enable an immersive fall hazard training program (Fig. 33.1). This platform helps trainees improve their fall hazard identification skills by providing: (1) a method to explore the construction environment and obtain detailed information by interaction; and (2) instantaneous feedback on their knowledge acquisition process. The platform was tested with trainees from construction-related disciplines to better elucidate how the platform transferred safety-related knowledge to participants.

33.2.1 Panoramic Augmented Reality Platform Development

The development of the platform was divided into four distinct phases to create the panoramic augmented experience, as illustrated in Fig. 33.2: capturing, authoring, immersion, and distribution. In the capturing phase, an equirectangular projection that recreates a 360° immersive view was obtained by employing a high precision panoramic camera (NCTech iStar Fusion) with multiple fish-eye lenses. This equirectangular projection was generated by stitching the images produced by each individual fish-eye lens into a single picture using computer software (NCTech Immersive Studio). In the authoring process, the captured projection was modified to resolve distortions introduced during the capturing process and projected in a 360° spherical context, enabling immersive exploration by the user.

During the immersion process, layers of fall hazard safety-related information were introduced to augment the environment captured. Interactivity was also added to the panoramic images using the game engine Unity3D®, allowing trainees to manipulate the different augmentations contained in the platform. This safety data immersion process is explained in detail in the next section. Ultimately, in the distribution process, the augmented panoramic scenes can be exported to different devices, allowing trainees using a plethora of devices—such as PCs, laptops, handheld devices, and head-mounted displays (HMD)—to access the interactive panoramic displays. In this study, PCs were targeted as the pilot testing device, as they were easily accessible, and did not require any special setup or additional external resources (e.g. game controller, HMDs, etc.). Moreover, interactive panoramas can be accessible online using cloud technologies which may enable real-time feed and big data analysis.

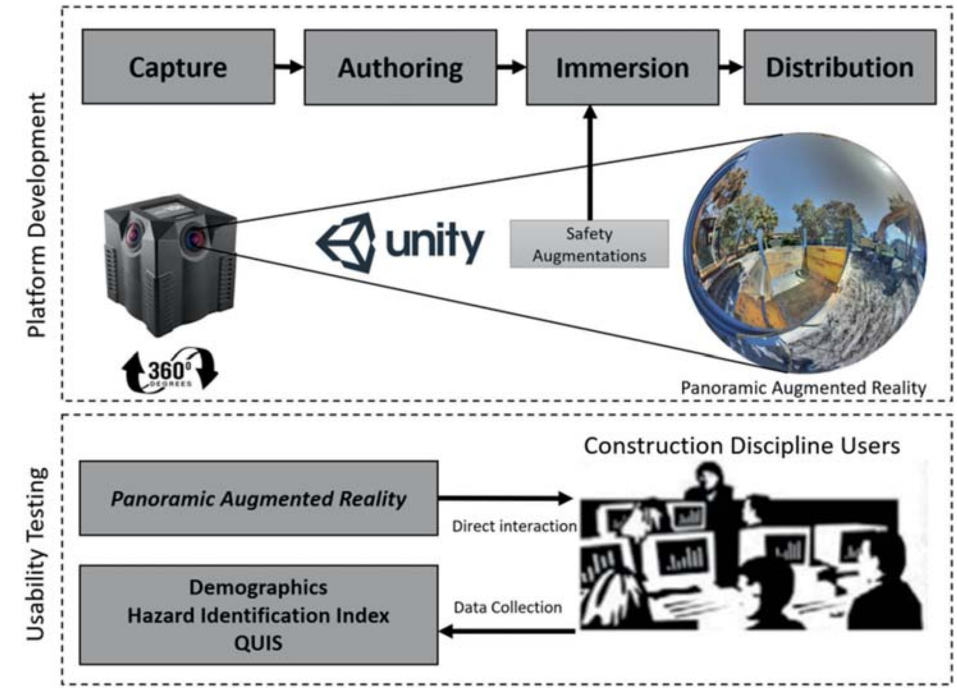
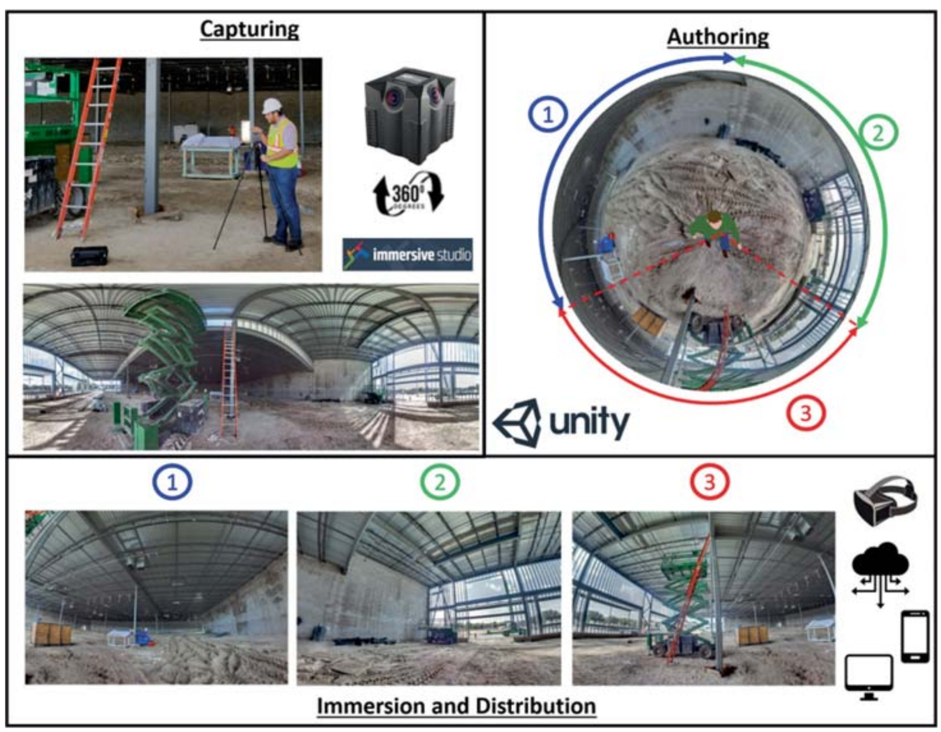


Fig. 33.1 Platform development and testing

Fig. 33.2 Interactive panorama creation



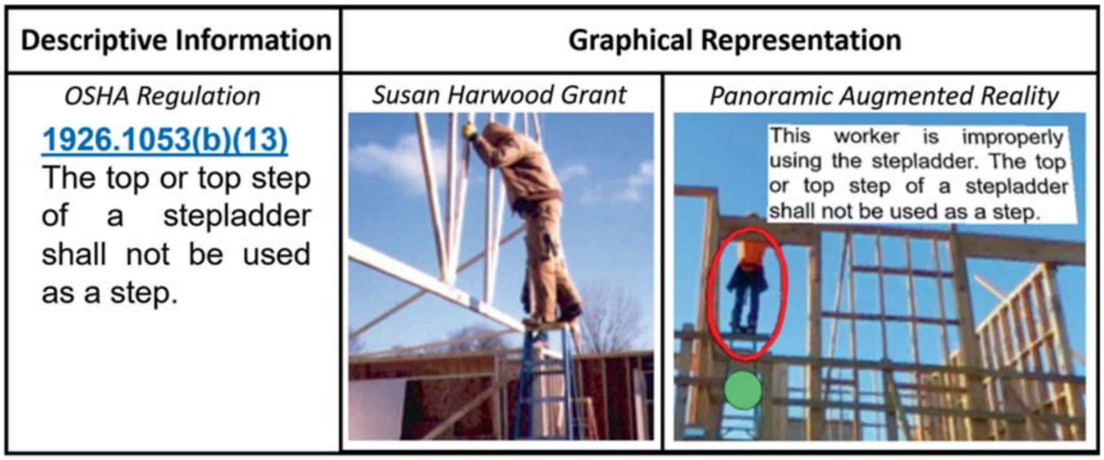


Fig. 33.3 Example of fall hazard augmentation

33.2.2 Fall Hazards Augmentations

Fall hazard-specific augmentations were developed for the platform based on OSHA regulations and the training materials provided by OSHA's Susan Harwood Grant Program (SHG). The content, descriptions, and pictures presented in the SHG training materials served as reference for the capturing, authoring, and immersion processes of the augmented reality materials. The augmentations developed for the panoramic images displayed descriptive information comparable to OSHA's regulations. Additionally, graphical representations of the hazardous conditions addressed in the platform were obtained in panoramic format, analogous to the contents in the SHG training materials. In this research, only four types of fall hazards were included in the training platform: ladders, edge protection, fall arresting, and housekeeping. The panoramic data collection for the pilot study was based on these four categories. All augmented materials developed for the platform required customized alterations of the OSHA and SHG contents, with the objective of facilitating similar learning outcomes to the trainees but in an immersive, interactive experience.

The presentation of the augmentations in the training platform was achieved using interactive hotspots that descriptively and graphically demonstrated OSHA's safety principles. Hotpots are click-based user interfaces that enable interaction with safety-data information, interconnecting the spatiotemporal location of the data and the information contained in the panoramic scenarios. For this study, these hotspots were green dots that when clicked by a trainee, showed a location marker and text with the fall hazard information. Figure 33.3. illustrates an example of content for fall hazards in the three different formats, specifically for stepladders. For this example, OSHA's regulation presents descriptive information using text to define a hazard related to stepladders. In the SHG, this information is presented by a graphical representation of the fall hazard. On the panoramic augmented reality platform, hotspot augmentations associate the descriptive information with the graphical representation using a red ellipse to denote the location of the hazard and text to describe the hazard, appearing only when the trainee interacts (mouse-click) with the interface.

33.2.3 Usability Testing

To evaluate the effectiveness of the developed platform in terms of knowledge acquisition about hazard identification and ease of use, human-computer interactions were assessed through a small-scale pilot study with real trainees. University of Florida's construction management and architecture students participated in the study. Three different instruments were used to collect data for the study: a pre-test survey, a hazard identification test, and a post-test survey.

The pre-test survey was administered to better understand the participant sample group, their previous knowledge regarding construction safety and the technology employed in the study. The survey gathered demographic information about age, gender, level of education, and educational focus. Questions were included to obtain information about each participant's construction experience, professional experience as a construction safety manager, and construction safety education. Additionally, participants self-assessed their level of understanding of augmented reality and 360° panoramic imaging.

The hazard identification test consisted of three different sessions: (1) training, (2) assessment, and (3) feedback. Sessions were consecutive and contained within the developed platform. In the training session (1), four different panoramic images, containing all the information trainees were expected to learn, were shown to the trainees as interactive augmentations. In this session, trainees were required to actively explore and interact with the panoramic locations to learn the fall hazard material presented. Immediately following, in the assessment session (2) trainees were shown sequential panoramic images without any augmentations and asked to identify all fall hazards. Data were collected within the platform, automating the data analysis process. When trainees had finished identifying the hazards in the assessment session, instantaneous feedback (3) was presented to the user on their previous hazard selections. For each image, the correct answer was displayed accompanied by Boolean "True" or "False" classifier, indicating correct (true) or incorrect (false) identification.

The evaluation of the hazard identification was performed using the hazard-identification index (adopted from Ref. [12]). The hazard-identification index (1) is defined as:

$$\mathrm{HII_j} = \mathrm{H_i}/\mathrm{H_{tot}} \tag{1}$$

The index was calculated for each trainee (j) based on the total number of identifiable hazards ($\mathrm{H_{tot}}$) in the immersive experience i. Safety professional determined the total number of hazards found the overall images. Hi indicates the number of hazards identified by the trainee j in the immersive experience i. To compute the total hazard-identification index for trainee j (*H*IIT, j), the mean of HIIj (2) was calculated across all scenarios for each hazards category:

$$H\mathrm{IIT_j} = Average(HII_{\mathrm{j}}) \tag{2}$$

The post-test survey centered on platform usability. Human-computer interactivity was assessed through a questionnaire with scaled numerical responses and open-ended sections for comments. The questionnaire was adapted from the Questionnaire for User Interface Satisfaction (QUIS), developed by University of Maryland researchers Chin et al. [13]. QUIS was specifically designed to test satisfaction with computer software and yield a high degree of accuracy. The newest version of QUIS (7.0) was adapted for this pilot study and included these sections: overall user reactions, screen, terminology and system information, and learning. Each section posed questions that asked respondents to rate the platform on a 1-to-9 Likert scale. The endpoint scores represented subjective adjectives (e.g., inconsistent/consistent), allowing trainees to express their thoughts regarding the platform [13]. Additionally, an open-ended question at the end of each section allowed trainees to provide supplementary comments that could not be reflected using Likert scales.

33.3 Results and Discussion

33.3.1 Participants

The sample size obtained for this pilot study was of 21 University of Florida students from Construction Management (76%) and Architecture (24%). The students were evenly distributed in Master's (57%) and PhD (43%) programs. In average, the participants had an age of 27 years, with a higher proportion of males (67%) than females (33%). The participants reported varying degrees of construction-related industry experience, ranging from less than 1 year (24%), 1 to 2 years (29%), 2 to 4 years (33%), to 4 to 10 years (14%) of experience. However, a large proportion (90%) of respondents did not report any construction industry safety-related experiences.

Many participants stated they previously taken a university-level course in construction safety (67%) and had received OSHA 30 safety certifications. No other type of safety education certification was reported by the participants. Overall, study participants reported that they had "some" to "fair" understanding of augmented reality technologies (none–5%; some–57%; fair–33%; competent–5%) and 360° panoramic technologies (none–14%; some–38%; fair–38%; competent–10%). Moreover, participants reported varying levels of understanding regarding general concepts of construction safety management (none–0%; some–38%; fair–38%; competent–24%) and OSHA regulations (none–10%; some–24%; fair–38%; competent–29%).

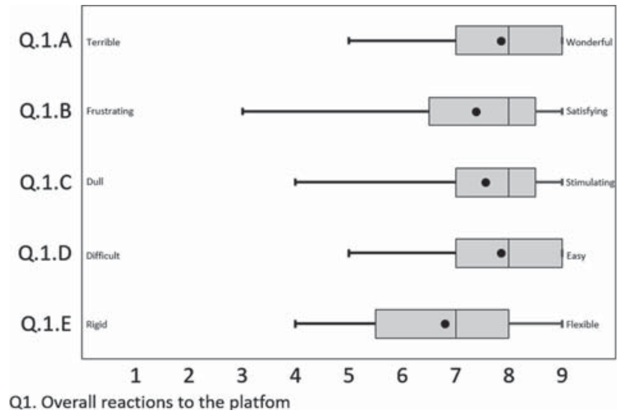


Fig. 33.4 Part 1: overall user reactions

33.3.2 Hazard Identification Index

A hazard identification index was calculated for each study participant, assessing ability to identify hazards within the developed platform. Participants identified an average 52% of the hazards presented in the assessment session. These findings are consistent with previous studies indicating that many hazards remain unrecognized on construction sites [12, 14]. This is alarming, since unrecognized hazards are the main source of incidents on construction sites.

Additionally, the proportion of participants who identified each hazard on each image was analyzed. The results obtained for each individual image were:

- Figure 33.1: ladder height-to-run ratio–86%; step-ladder improper usage–43%; improper guardrail installation, placement, or fully missing–24%; untied worker–14%
- Figure 33.2: step-ladder improper usage–71%; improper guardrail installation, placement, or fully missing–57%
- Figure 33.3: improper guardrail installation, placement, or fully missing–48%; incorrect material storage–86%
- Figure 33.4: incorrect material storage–43%; untied worker–62%; hazardous electrical cord–43%

For each individual image, most participants were able to detect the improper usage of ladders and unsafe storage material. Nevertheless, only a small number of participants were able to identify improper usage of fall protection system (i.e. untied worker) on Fig. 33.1 but were able to identify a similar condition on Fig. 33.4. It is notable that since a limited number of images were used in this study, no generalizations can be made in terms of these results.

33.3.3 Platform Usability

The overall responses of participants regarding the developed platform were favorable (Fig. 33.4). The platform was perceived as wonderful (Mean: 7.9; Median: 8.0; IQR Low: 7.0; IQR High: 9.0), satisfying (7.4; 8.0; 6.5; 8.5), and stimulating (7.6; 8.0; 7.0; 8.5) to use, with narrow distributions of responses. The platform was also rated as easy to use (7.9; 8.0; 7.0; 9.0) and flexible (6.8; 7.0; 5.5; 8.0), presenting a compact distribution. Moreover, participants provided positive comments on the platform as a method to learn about fall hazards. For example, one participant commented that "*[the platform] is a good way to learn about site hazards*," and another remarked that "*[the platform] was very easy to use*."

Participants also provided favorable feedback about the elements shown on the screen of the platform throughout the tasks assigned (Fig. 33.5). The fall hazard materials contained in the augmentations were reported as easy to read (8.1; 8.0; 7.5; 9.0). The augmentations contained sharp (7.4; 8.0; 6.5; 8.5) and very legible (8.4; 9.0; 8.0; 9.0) characters. The highlighting that the augmentations introduced on screen was very helpful (8.3; 8.0; 8.0; 9.0) in allowing participants to locate the hazards. Additionally, the amount of fall hazard information displayed (7.9; 8.0; 7.0; 9.0) on screen by the hotspots and the arrangement of that information (8.2; 8.0; 8.0; 9.0) was adequate and logical. The flow of the platform was positively perceived by the participants, as they stated that the sequence of screens (8.4; 9.0; 8.0; 9.0) and the progression of tasks (8.1;

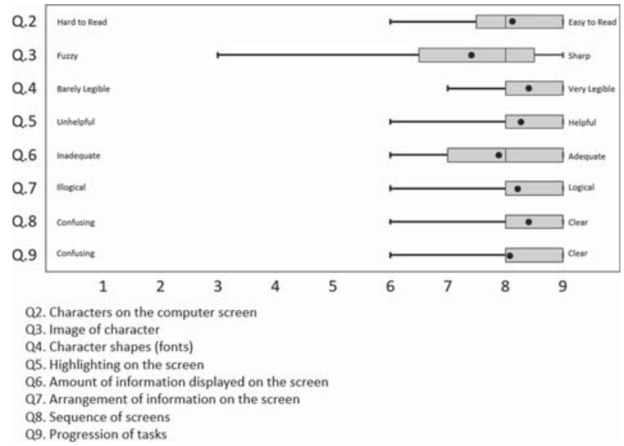


Fig. 33.5 Part 2: screen

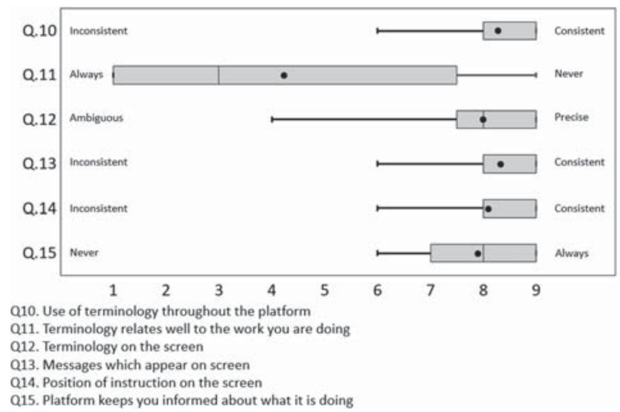


Fig. 33.6 Part 3: terminology and platform information

8.0; 8.0; 9.0) were clear and simple to follow. One participant commented that "*the hazards were shown clearly in the training [session]*," but another said that "*in the assessment [session], it was troublesome to finding some hazards*."

Feedback on the terminology and the platform information indicated generally positive results as shown in Fig. 33.6. Participants considered the fall hazard terminology employed in the platform to be consistent (8.3; 9.0; 8.0; 9.0) and precise (8.0; 8.0; 7.5; 9.0), although some terminology occasionally appeared to be disconnected with the specific tasks performed (4.3; 3.0; 1.0; 7.5). Moreover, the platform messages on screen (8.3; 8.0; 8.0; 9.0) and the position of messages (8.1; 8.0; 8.0; 9.0) that contained task instructions were considered consistent, as the platform tended to keep participants informed (7.9; 8.0; 7.0; 9.0) on what they were doing about a specific task.

Finally, the participants expressed the tasks that required to learn how to identify hazards in the platform were simple to learn as shown in Fig. 33.7. The platform operations were easy (8.3; 9.0; 8.0; 9.0), as the task could be often performed in a straight-forward manner (8.3; 9.0; 8.0; 9.0). There was adequate number of steps to complete the tasks (8.2; 8.0; 8.0; 9.0) and these followed a logical order (8.2; 8.0; 8.0; 9.0). Additionally, the feedback provided to the participants was reported to be clear (7.4; 8.0; 7.0; 9.0), allowing an understanding of what the hazards presented in each of the images shown in the assessment session.

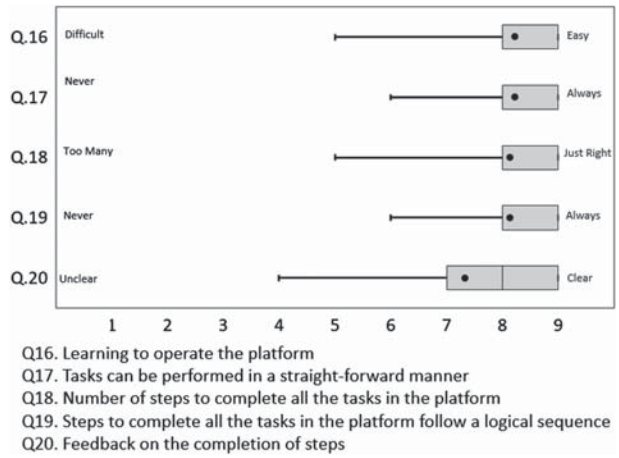


Fig. 33.7 Part 4: learning

33.3.4 Lessons Learned

Qualitative comments obtained from the participants provided valuable insight into major issues with the platform that must be addressed in the future. The responses collected were classified in five categories: (1) image quality; (2) safety information displayed; (3) interface visual and interactions; (4) hazard navigation; and (5) general recommendations.

Several participants noted that image quality (1) was an issue for hazard identification as "the resolution of specific points [in the images] are not high enough". This comment reflected current limitations of the 360° panoramic technology, as other participants noted that "*the quality of the images could improve" as there are some parts of the images where it was difficult to see or identify the hazards*." Because fall hazard identification relies on intrinsic detail found in the images, some participants expressed that "*a higher resolution on imaging would produce a better experience*". In the platform, several issues were raised by the participants regarding the safety information displayed (2) on screen. Some participants stated that in the training session the "*[hazard] identification descriptions were not clear*" and "*some of the hazards explanations on the screen were not clear when it moved in certain directions or faced a certain way*." Additionally, one person commented that "*[fall hazard] information was only shown in one image but was present in multiple images*" producing confusion because it was not clear if those were the same type of hazard or different independent hazards.

The interface (3) used by the participants also had design problems both in the visual aesthetics and the interactions. Some participants reported that in the feedback section "*fonts were too small and not as appealing as the rest of the platform*" The hotspots also caused some problems because in some of the locations "*the green highlights and the circles overlapped*." Moreover, the participants conveyed that in the training session they had difficulties assessing "*how many hazards are present in an image and were to look for them*", suggesting that "*it could be easier for the trainee to see the number of hazards on the screen to be aware and not miss any hotspots*." Other participants described interaction problems that included "*scrolling and panning direction*" and "*buttons did not easily switch between hazard types*." The platform hazard navigation (4) also was concerning for several participants who stated that "*it is only possible to see what is going on directly near you. For example, it was unclear if the people in one of the images were on an area that needed harness*." In general, participants recommended (5) that the platform could be improved by integrating audio as "*some people might understand or learn better when they are doing both listening and visualizing things*" or video to "*show the user the right way of doing things*."

33.4 Conclusion and Further Work

Panoramic augmented reality has the potential of providing an immersive safety training experience for construction workers and professionals. This paper described the process of creating a platform using 360° panoramic images augmented with fall-related hazard information based on OSHA and SHG training materials. The development required four steps: capture, authoring, immersion, and distribution. A pilot study was performed to assess the platform's ability to enhance learning about fall hazards identification and the overall usability of the interface. The results indicated that an average 52% of fall hazards were recognized by study participants. Positive feedback was obtained regarding participant usability of the platform. The participants expressed that the platform was overall easy to use and flexible, especially highlighting that the augmentations introduced on screen were very helpful in locating the fall hazards. Nevertheless, the participants indicated that several improvements needed to be addressed to provide a better overall experience.

Future research should investigate the ability of panoramic augmented reality to provide trainees with hazard identification knowledge about other types of hazards (e.g., caught-in, struck-by, electrical). Further, a larger sample size is required to perform a statistical analysis of participants' hazard-identification skills that would yield significant results. Finally, the incorporation of video, audio, and Building Information Models (BIM) in the platform should be explored to determine their impact on trainees' hazard identification skills

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