Suitability and Effectiveness of Visualization Platform-based Construction Safety Training modules

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Abstract –

The construction industry is one of the most hazardous industries in the world. In addition, past literature highlighted that about 50% of the hazard remains unrecognized in the construction work environment, resulting in catastrophic consequences. Construction Safety Training (CST) is one of the best safety interventions to deal with this. The traditional classroom-based CST method is fraught with several non-interactive, non-engaging, and ineffective limitations. With the advent of visualization platform-based technologies, researchers have introduced various CST delivery modules using digital environments. However, in-depth investigation of visualization platform-based safety training modules from a suitability and efficacy perspective for the construction industry is understudied. Therefore, this study aimed to identify a suitable and effective safety training delivery module for the construction industry. To this end, three visualization platform-based CST modules were developed, namely, Image, Virtual Tour (VT), and Mobile Virtual Reality (MVR), and introduced to the construction professionals. The feedback analysis highlighted that VT CST is suitable for the industry. Next, the effectiveness of the VT CST modules was determined using Hazard Recognition Score (HRS). The results highlighted that the overall pre-training HRS of the construction professionals was 56.83%, and post-training HRS was 88.56% which shows significant (p < 0.00) enhancement in the HRS. In conclusion, this study noticed the VT CST module as a suitable and effective training module for the industry. Further, theoretical and practical implications of the study and future research directions were discussed.

Keywords –

Construction; Hazard; Safety; Training; Visualization

1 Introduction

The construction industry continues to be one of the hazardous industries in the world due to associated risky work practices and complex and dynamic nature [1]. On one end, it is one of the significant pillars in the economic development of several countries [2]. On the other end, globally, it is responsible for more than 60,000 mortalities every year [3]. Accident numbers vary from country to country [4]. For example, the construction industry in the developed economy such as the United States of America is responsible for over 900 mortalities and 200,000 non-fatal injuries in 2016 [5]. At the same time, the construction industry in the developing economy such as India is responsible for mortalities ranging from 11,614 to 22080 [6]. These statistics provide a snapshot of the hazardous nature of the construction industry worldwide. Consequently, construction safety management research has attracted the attention of academicians and practitioners from all over the world [7].

The root cause analysis of the industrial accident was performed by H. W. Heinrich and identified unsafe behavior (88%), unsafe conditions (10%), and natural disaster (2%) as root causes of the industrial accidents [5], [8]. 98% of accidents can be eliminated by practicing safe behavior and maintaining safe site conditions [9], [10]. For instance, by focusing on major victims of construction accidents, i.e., workers, they can secure their safety by safe behavior and either accepting or rejecting the risk involved in the work assigned [11]. In the current scenario, even though the employer is safety conscious, workers can decide to behave either safely or unsafely [11]. Also, workers' ability to recognize the hazard and understand the magnitude of risk involved determines their behavior and safety [11]. However, studies highlighted that construction workers do not possess the essential skill sets to recognize hazards correctly [7], [12], [13]. Consequently, poor hazard recognition leads to construction accidents [14]. More specifically, about 50% of the hazards remain unrecognized in the construction work environment [5], and such poor hazard recognition and assessment are responsible for more than 42% of the construction accidents [15].

Past literature has highlighted that safety training is one of the best methods of improving hazard recognition skills of the construction workforce [1], [11]. It can be ascertained that several employers invest millions of dollars in training their employees for hazard management and preventing accidents [1]. Notwithstanding such initiatives from the employers, the desirable level of hazard recognition has not been reached [13]. Past studies have highlighted that only 10% to 15% of training investments result in expected outcomes in the jobsite [1], [16] and have not noticed a positive correlation between implementing traditional safety training methods and safety performance [17]. Whereas on-site demonstrations of hazards for training purposes are subjected to injury risk, often time-consuming and costly [18], [19].

In recent years, visualization platform-based safety training modules have been introduced in the safety training domain to overcome the drawbacks of the traditional safety training methods. The visualization platform-based safety training modules depict actual construction sites in the digital environment. Such a digital environment replicates hazardous construction site conditions that are impossible to observe, unsafe behavior that is dangerous to perform, and costly to develop in an actual construction work environment [20]. Consequently, visualization platform-based safety training modules such as Image, VT, and MVR CST methods have captured the attention of the researchers. Past research has explored the usability of visualization platform-based safety training modules [19]. However, the detailed investigation of the effectiveness of a suitable visualization platform-based CST method is understudied. Therefore, this study aimed to identify the effectiveness of the suitable visualization platform-based CST module. The objectives of the study were two-fold,

- To identify a suitable visualization platform-based CST module,
- To determine the effectiveness of a suitable visualization platform-based CST module.

2 Background of the study

Hazard is the potential of something to cause harm [21]. Hazards may be predictable as part of planned tasks or emergent due to the industry's dynamic nature [11]. At present, hazard recognition is solely relied on safety officers [22]. At the same time, a past study highlighted that about 50% of the hazards remain unrecognized in the construction work environment [5] due to the industry's dynamic nature, varied safety perception levels, and limited numbers of safety officers [22]. On one end, studies reported that hazard recognition is the safety officer's responsibility [22], and on the other end, safety is the responsibility of all stakeholders. In addition, small-budget construction projects and safety-insentient organizations often do not engage safety officers. Therefore, developing and enhancing the hazard recognition abilities of the major stakeholders is imperative [23]. As a first step, this study considered major stakeholders such as construction workers and site supervisors as target subjects. Past literature has continuously highlighted that safety training is one of the best interventions to develop and enhance hazard recognition skill sets among construction stakeholders [1].

Safety training enhances employee safety knowledge, perception, behavior, compliance, and safety culture and performance [24], [25]. As a result, safety training interventions have been a point of attraction for the last four decades. Some of the studies focused on safety training delivery methods, whereas some on safety training knowledge transfer. For instance, Cromwell and Kolb [16] highlighted that trainees with a high level of organization, supervisor, and peer support reported higher safety knowledge transfer. Past studies [25], [26] also highlighted that traditional safety training delivery method such as classroom-based safety training needs to be improved for effective knowledge transfer. Consequently, researchers have introduced visualization platform-based safety training modules [5], [7], [11], [17], [19], [20], [27]–[30]. However, a systematic investigation on the suitability of the visualization platform-based safety training modules for the construction industry and the effectiveness of such a suitable safety training method is understudied. This investigation can strengthen safety training delivery and boost knowledge transfer by adopting a suitable and effective safety training module for the industry.

3 Research methodology

The aim of the study was achieved in two phases. The first phase focused on developing visualization platform-based CST modules and identifying a suitable training module for the construction industry. The second phase focused on investigating the effectiveness of the suitable visualization platform-based CST module.

3.1 Visualization platform-based construction safety training modules and their suitability

This study developed three CST modules: Image, VT, and MVR CST. Here, the Image-based CST module includes virtual photographs along with associated safety information. The VT CST module contains a virtual tour around the simulated construction scenario. Here, users were provided with safety information while exploring the digital construction work site. The third CST module was MVR, which was based on the gaming platform. A simulated construction scenario was introduced to users through a virtual reality gearbox using a mobile device. In this module, the user had the freedom to comprehend safety practices while exploring simulated construction scenarios using a gaming joystick.

The content for CST modules was based on general safety practices related to personal protective equipment (PPE), scaffolding, construction machinery, and material storage. A total of 21 safety practices were considered from Bhagwat et al. [19], adopted from various Bureau of Indian Standards and a safety handbook. One of the examples out of the considered 21 safety practices was 'Worker on site with proper PPE'. Simulated construction scenarios were developed considering 21 safety practices and using Trimble SketchUp, Autodesk Revit, and Unity game engine. Based on developed simulated construction scenarios, Image, VT, and MVR CST modules were developed as shown in Figures 1, 2, and 3, respectively.

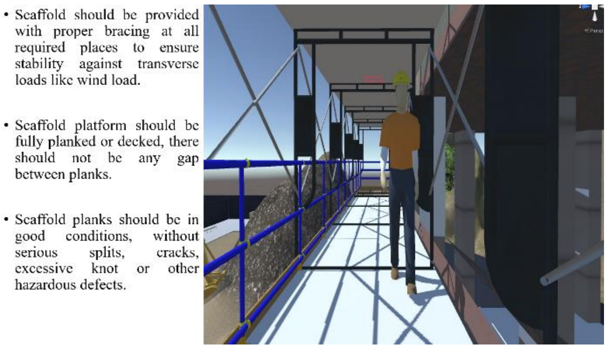

Figure 1. Screenshot of Image CST module

Figure 2. Screenshot of VT CST module

Developed CST modules were introduced to construction professionals, and their views regarding suitable safety training module for the construction industry was identified through a questionnaire survey.

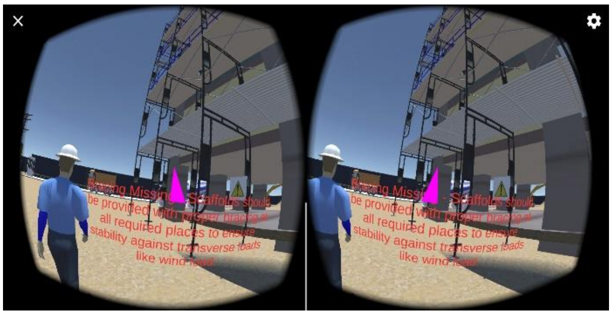

Figure 3. Screenshot of MVR CST module Note: Bracing missing- scaffolds should be provided with proper bracing at all required places to ensure stability against transverse loads like wind load.

3.2 Effectiveness of the suitable CST module

The effectiveness of the suitable CST modules was evaluated using the HRS of the construction workers and supervisors. To do so, adopted 21 safety practices were negatively coded and considered for the HRS assessment. The relative average hazard weight associated with 21 unsafe practices was adopted from Bhagwat et al. [19] to evaluate the HRS, as shown in table 1. For example, the relative average hazard weight of 'Worker on site without proper PPE' was 5.12%. The sum of all relative average hazard weights for all unsafe practices was 100%. If any respondent identified all hazards during the HRS assessment, then the respondent was awarded 100% HRS. If any respondent did not identify a single hazard was awarded 0% HRS. Here, to investigate the effectiveness of the suitable CST module, pre-training and post-training HRS of construction workers and supervisors were determined through an experimental study.

Table 1. Relative average hazard weight (%) of the unsafe practices (adapted from Bhagwat et al., [19] with permission from ASCE)

Unsafe practices	Weight (%)
Workers without safety helmet	5.58
Crane member close to overhead power lines	5.58
Person being lifted by crane on its hook or boom	5.53
Unstable or uneven scaffold footing	5.48
Scaffold bracing is missing	5.38
working on the scaffold without safety belt	5.33
Working platform with cracks	5.17
Worker on site without proper PPE	5.12
Nails/Bars being projected out	4.97
Working platform is missing	4.87
Guardrail not provided	4.61

Obstruction on working platform	4.61
Scaffolding ladder without railing	4.56
Use of ladder on scaffold	4.56
Worker sitting on gas cylinder.	4.51
Toe Boards is missing	4.46
Stack of cement bags higher than 15	4.10
Guardrail top railing missing	4.00
Scaffolds platform not fully planked	4.00
Cement bags stack higher than 8 without crosswise pattern	3.79
Worker handling cement without goggles and dust mask	3.79

4 Data collection, analysis and results

4.1 Suitable CST module

As mentioned earlier, this study developed three visualization platform-based CST modules. Further, a questionnaire survey was conducted through construction professionals to identify a suitable CST module for the industry. A total of 47 construction professionals were approached using the snowball sampling technique. Out of which, 45 responses were recorded, with a response rate of 95.74%. All responses were collected through face-to-face interactions, which resulted in a higher response rate and precise inputs. The respondents' designation (as shown in Figure 4) and work experience (as shown in Figure 5) details highlighted that the respondents had varied roles in the construction industry with varied work experiences. The total experience of the respondents was 352 years, and the average experience was more than 7.5 years. Such diverse roles and work experiences helped to maintain quality and unbiased responses.

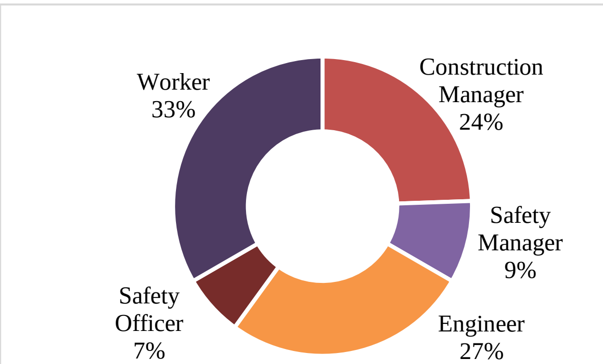

Figure 4. Construction professionals' role in the construction industry

Further, the data analysis was performed, and a suitable safety training module was identified for the construction industry. Out of 45 respondents, eight (18%) respondents selected Image, eight (18%) respondents selected MVR, and 29 (64%) respondents selected VT as a suitable safety training module for the construction industry, as shown in Figure 6. Broadly, according to construction professionals, the VT CST module is a suitable module for the industry. However, more in-depth investigations in this domain are warranted to confirm the generalizability of the results.

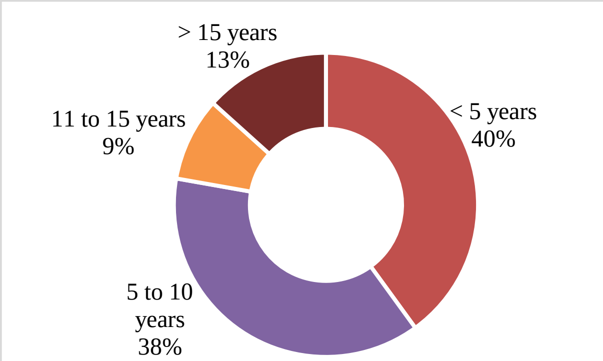

Figure 5. Construction professionals' work experience in the construction industry

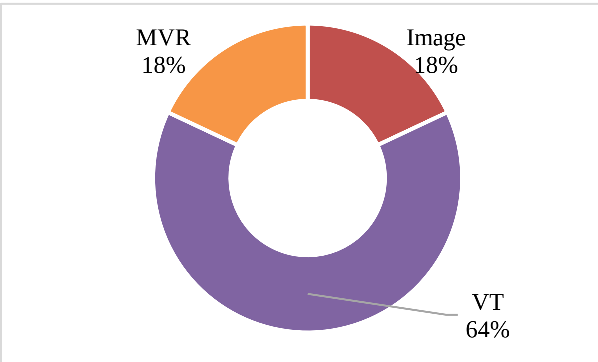

Figure 6. Construction professionals' percentage preferences to the CST modules

4.2 Effectiveness of VT CST module

The study's second objective was achieved using pre-training and post-training HRS of construction workers and supervisors. In this experimental study, fifteen respondents participated from three different building construction projects. Out of fifteen, twelve respondents were workers, and three were site supervisors. The total experience of the respondents was 104 years, and the average experience was more than 6.5 years. Out of three projects, two were residential, and one was a commercial building construction project. All three projects were located in Mumbai city, Maharashtra, India. Before initiating the experimental study, all the respondents were introduced to the study's objective, and their consent was obtained. Further, respondents' pre-training HRS assessment was conducted. A sample photograph of the pre-training HRS assessment is shown in Figure 7. The pre-training HRS were calculated using Equation (1).

$$HRS = \sum_{i=1}^{21}(p_i)\,(q_i) \tag{1}$$

Where, p_i = relative average hazard percentage weight, i = 21 unsafe practices considered in the assessment, and q_i = (0, 1) if unsafe practice i was identified, then q_i = 1, else 0. All pre-training HRS are given in Table 2. For example, the pre-training HRS of respondent 1 was 70.80%. After the pre-training HRS assessment, safety training was provided to all respondents using the VT module. The training was provided with the help of a tablet. A sample photograph of the VT safety training is shown in Figure 8. The training time for each respondent was seven minutes. After safety training, a post-training HRS assessment was conducted, and HRS were calculated using Equation (1). All post-training HRS are given in Table 2.

Figure 7. Sample photograph of pre-training HRS assessment

4.3 Statistical differences between pre-training and post-training HRS

Based on the initial observation in Table 2, there were differences in construction professionals' pre-training and post-training HRS. Therefore, these HRS differences were further statistically evaluated with the help of hypothesis testing. The null hypothesis *(H_0)* was set as construction professionals' post-training HRS were lesser than pre-training. The alternative hypothesis *(H_1)* was set as construction professionals' post-training HRS were greater than pre-training. A One-tail t-test for paired two samples for means was performed at the confidence interval of 95%. The hypothesis test result rejected H_0 ($p < 0.00$), i.e., the post-training HRS were greater than the pre-training HRS. This highlighted the effectiveness of the VT CST module.

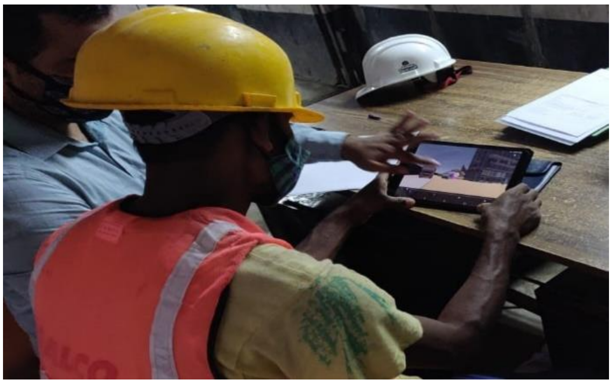

Figure 8. Sample photograph of VT safety training to construction professional

Table 2. Construction professionals' HRS in pre-training and post-training safety assessment

Respondent code	Pre-training HRS (%)	Post-training HRS (%)
Worker 1	70.80	90.29
Worker 2	32.37	82.35
Worker 3	47.74	81.64
Worker 4	56.37	95.83
Worker 5	88.40	90.70
Worker 6	59.73	95.83
Worker 7	45.31	69.19
Worker 8	36.91	73.69
Worker 9	50.48	85.93
Worker 10	72.20	95.72
Worker 11	49.41	81.99
Worker 12	53.97	92.81
Supervisor 1	60.93	100.00
Supervisor 2	67.59	98.11
Supervisor 3	60.29	94.32

5 Discussion

This study performed a systematic investigation of visualization platform-based CST delivery methods based on suitability and efficacy for the construction industry. A total of 21 practices were considered for the investigation purpose. As a next step, this study developed three visualization platform-based CST modules such as Image, VT, and MVR. According to the data analysis, 64% of the construction professionals favored the VT module as a suitable CST module for the industry. Construction professionals have preferred the VT based on time (quick safety training compared to Image and MVR), cost (cost-effective compared to MVR), ease to use compared to MVR, and little trainer intensive [19].

Further, the levels of hazard (percentage weights) were evaluated with the help of experienced construction professionals' inputs. The effectiveness of the VT CST module was investigated through workers and supervisors. The lowest HRS for workers pre-training was 32.37%, and the highest HRS was 88.40%. The post-training lowest HRS for workers was 69.19%, and the highest HRS was 95.83%. On average, the pre-training HRS for workers was 55.31%, and the post-training HRS was 86.33%, as shown in figure 9. The pre-training lowest HRS for supervisors was 60.29%, and the highest HRS was 67.59%. The post-training lowest HRS for supervisors was 94.32%, and the highest score was 100.00%. On average, the pre-training HRS for supervisors was 62.93%, and the post-training HRS was 97.47%, as shown in figure 9. The overall pre-training HRS was 56.83%, and post-training HRS was 88.56%, as shown in figure 10.

Broadly, the results revealed that with a single training session of seven minutes, the HRS for the workers was enhanced by 31.02%, for supervisors by 34.54%, and overall by 31.73%. The statistical analysis also supported noticed HRS enhancement and concluded that pre-training and post-training scores are significantly different at the confidence interval of 95%.

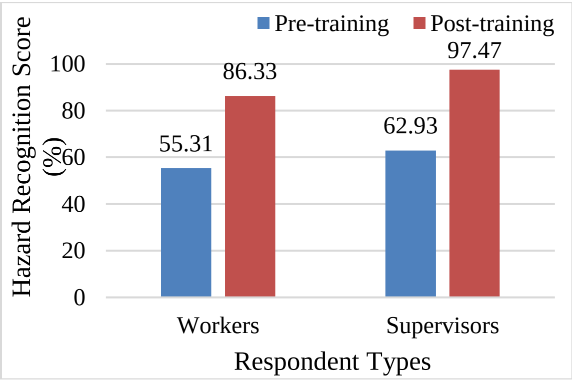

Figure 9. Pre-training and post-training HRS of workers and supervisors

This study also noticed interesting findings that construction professionals identified 56.83% of hazards, and about 43.17% of hazards were unrecognized. These findings are somewhat in line with the past study highlighting that about 50% of hazards remain unrecognized in the construction environment [5]. In fact, there is an improvement in the HRS and a percentage reduction in unrecognized hazards, which is a good sign for the construction industry. To sum it up, this study noticed that VT CST is a suitable safety training delivery method for the industry and an effective safety training method for knowledge transfer.

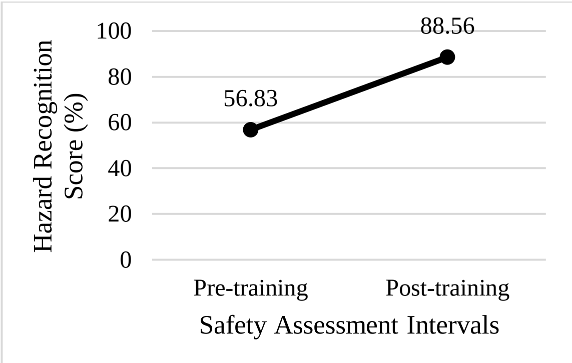

Figure 10. Overall HRS for pre-training and post-training HRS assessment

6 Conclusion

This study aimed to identify a suitable and effective visualization platform-based safety training module for the construction industry. As a first step, three visualization platform-based CST modules were developed, and VT was identified as a suitable safety training module for the construction industry. Here, the suitability of the modules presented an initial Next, the effectiveness of the VT CST module was evaluated. The efficacy of the VT CST was confirmed based on significantly ($p < 0.00$) enhanced HRS from 56.83% to 88.56% using single-time safety interventions.

As mentioned earlier, findings on the suitability of the CST modules need to be sharpened in the future with more in-depth investigations. Next, recently, 360-degree panorama, Mixed reality, and other visualization platform-based safety training methods have been introduced to the construction safety domain. Future research studies can focus on mentioned advanced safety training delivery methods for further in-depth investigation. The theoretical contribution of the study is to perform a comparative analysis of advanced visualization platform-based CST modules and identify suitable and effective safety training delivery and knowledge transfer module for the construction industry. The practical contribution of the study is construction professionals can develop and adopt personalized VT CST modules for training construction stakeholders and to enhance their hazard recognition capabilities and safety performance of the project.

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