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ENHANCING SAFETY TRAINING AND HAZARD IDENTIFICATION IN CONSTRUCTION PROJECTS USING 360-DEGREE PANORAMIC IMAGES

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SUMMARY: *Accidents in the Egyptian construction industry are rising due to insufficient worker safety knowledge. While traditional safety training methods are widely used, they are often ineffective and uninspiring. This research presents the first immersive, game-based safety training platform specifically tailored to the Egyptian construction industry, integrating augmented 360-degree panoramic images captured from real local job sites. The methodology comprises of three stages: 1) identifying safety practices, 2) platform development, and 3) platform evaluation and statistical analysis. In the first stage, safety experts were interviewed to identify current safety practices and the most frequent hazards in Egyptian construction sites. In the second stage, Platform Development, started with capturing 360-degree images from construction sites, identifying the safety hazards in the captured images, and identifying the associated OSHA standards with safety experts for game development. A game platform was developed using Unity 3D, featuring four interactive scenes: Educational, Assessment, Explanation, and Hazard Controls. The platform integrates Unity's built-in features and C# scripting to create an interactive and immersive experience. In the final stage, 30 construction practitioners from two construction sites in Egypt tested the platform, evaluated its user interface, and assessed the quality of the 360-degree images. Feedback was collected through a questionnaire and analyzed using statistical analysis. Results showed that 92% of participants positively rated the user interface, and 97% recommended the platform as a safety training tool. This research offers a first-of-its-kind digital solution that addresses the gap in immersive safety training in Egypt, enhancing hazard recognition and knowledge retention through real-world simulation.*

KEYWORDS: *Construction Safety Training, 360-degree Panoramic Images, Hazard Identification, Augmented Panoramas, Virtual Reality.*

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1. INTRODUCTION

The construction industry is among the most hazardous sectors worldwide, consistently reporting high rates of workplace injuries and fatalities. In the United States, fatal injuries in construction increased by 39.8% from 2011 to 2022 and by 7.6% from 2021 to 2022 (Trueblood et al., 2024) .In 2022, the US Bureau of Labor Statistics reported 1,056 fatal work injuries in the construction sector, representing 19% of all fatal work injuries in the US. Falls, slips, and trips were the leading causes, contributing to 40% (423) of these deaths (US Bureau of Labor Statistics, 2023) Construction sites present unique challenges that hinder the standardization of safety practices, including project variability and a lack of worker safety knowledge (Elsebaei et al., 2020).

Safety training is crucial to enhance safety knowledge among construction workers allowing them to be more proactive when dealing with unsafe working conditions (Dang et al., 2024). However, traditional training methods, such as lectures and 2D videos, are often ineffective. Research has shown these approaches lead to reduced trainee engagement and limited hazard recognition during site inspections (Isingizwe et al., 2024).

Emerging technologies, particularly virtual environments, offer innovative solutions to enhance safety training. Platforms utilizing 360-degree panoramas provide realistic yet controlled scenarios for hazard identification and response, improving engagement, retention, and learning outcomes (Eiris & Gheisari, 2022). Techniques such as immersive storytelling and online multiuser virtual site visits have shown significant benefits over traditional methods, demonstrating increased trainee engagement and safety knowledge retention (Isingizwe et. al, 2024).

The Egyptian construction industry is experiencing a rapid expansion, with mega projects such as the New Administrative Capital and renewable energy facilities scheduled for completion by 2025. However, this growth has been accompanied by high accident rates, with construction consistently ranking as one of the top three sectors for workplace injuries, recording 539, 645, and 634 accidents in 2015, 2016, and 2017, respectively (Elsebaei et al., 2020). Studies conducted about safety management in Egypt primarily focused on identifying the factors impacting safety performance and the leading causes of site accidents. Contributing factors include inadequate safety enforcement, insufficient governmental oversight, and limited safety training (Abdalfatah et al., 2023). Taha et al. (2024) assessed the safety training content, related to scaffolds and falling objects hazards, provided in a large-sized construction company via traditional safety training methods and it was concluded that the content addressed almost all the safety requirements imposed by OSHA.

Despite the documented benefits of immersive training tools, their application within Egypt's construction sector remains significantly underexplored, particularly given the ongoing challenges related to regulatory enforcement, training engagement, and high accident rates. This study addresses a critical, context-specific gap by developing a safety training platform grounded in actual Egyptian jobsite conditions and shaped by input from OSHA-certified local experts. Although OSHA is not officially mandated in Egypt, its standards are widely adopted by mid- to large-sized firms, particularly those with international partnerships; making OSHA standards a practical benchmark for this research. The proposed methodology leverages augmented 360-degree panoramic images to create a game-based platform that enhances hazard identification, mitigation planning, and control implementation. It follows a three-stage approach: (1) identifying safety practices, (2) developing the interactive training platform, and (3) evaluating its effectiveness through statistical analysis. While tailored to Egypt, the platform's immersive, low-cost structure offers strong potential for broader adoption in other developing countries facing similar construction safety challenges.

2. LITERATURE REVIEW

Mohammadi et al. (2018) summarized the sub-factors influencing safety performance in construction projects into, motivation, adoption of safety rules and regulations, safety training and knowledge, safety behavior, work pressure to accelerate the job, and lessons learned from accidents. To conclude, safety performance is impacted not only by the project but also the government, the organization, and the workers. Abdalfatah et al. (2023) also determined 11 factors and stated that the two most important factors affecting safety performance are incentives and safety training. The findings show that safety behavior accounts for 88% of accidents on construction sites (Mohammadi et al., 2018). While prior research has identified causes of accidents, limited attention has been paid to understanding unsafe behaviors and controlling them.. Thus, (Fang et al., 2016) developed a five-level Cognitive Model of Construction Workers' Unsafe Behaviors (CM-CWUB) and analyzed the causes that led to the failure of the CM-CWUB. The model includes: 1) obtaining information, 2) understanding information, 3) perceiving responses, 4) selecting responses, and 5) taking actions. This cognitive model can help perceive unsafe behaviors and develop effective solutions to reduce such behavior.

Safety training in the construction industry has evolved significantly, as improved training correlates with better hazard identification skills and fewer site accidents. Başağa et al. (2018) studied the effectiveness of safety training in Turkey and concluded that the level of employee's education and the use of interactive safety training methods would benefit the workers. However, traditional safety training lacks the immersive state resulting in low engagement of trainees (Lin et al., 2023). Raeisinafchi et al. (2024) explored the innovative methods adopted for safety training like storytelling, humor, and simulations, combined with modern technologies like virtual reality (VR), augmented reality (AR), and artificial intelligence (AI) which have demonstrated advantages in enhancing knowledge retention and engagement. Despite these benefits, studies have noted resistance among construction workers to adopting such technologies due to unfamiliarity and perceived complexity.

Hasanzadeh et al. (2017) highlighted the importance of safety training by measuring the impact of safety knowledge on the worker's hazard identification skills using eye-tracking technology. It was found that more experienced workers had better hazard identification skills which show that safety training is essential for accident reduction. Hasanzadeh et al. (2017) also recommended developing more interactive training techniques. Safety training has been improved by using VR to deliver safety training in which simulations are developed to represent real-world conditions. VR-based simulations have been shown to provide immersive learning experiences, overcoming language barriers and improving knowledge retention (Bakhoum et al., 2023). Hilfert et al. (2016) also found that VR effectively engages users by simulating real-world conditions, while (Bin et al., 2019) integrated vibration tables to create a highly immersive experience in traffic construction safety education. Wolf et al. (2022) has also used VR to develop immersive safety training programs and concluded that VR improved knowledge retention. Dhalmahapatra et al. (2021) evaluated the effectiveness of VR-based simulator that was used as a safety training tool. It was concluded that VR-based training can be a valuable supplement to conventional approaches, offering a safer and more engaging method. Furthermore, (Yu et al., 2022) has evaluated the use of immersive virtual reality (IVR) in safety training and compared its impact on novice and experienced construction workers. It was also concluded that IVR-based training improved safety performance for both groups. Guo et al. (2024) also used VR to compare hazard identification performance in virtual environments with traditional safety training methods using different learning styles. It was concluded that VR was more effective especially for the participants who prefer visual learning styles. Speiser and Teizer (2023) also developed a methodology that leverages digital twin data to automatically generate immersive VR training environments grounded in real construction schedules and spatial configurations. Their approach identifies struck-by hazards using the intersection of simulated workspaces and object drop zones over time, enabling hazard zones to be visualized and updated dynamically. Lemouchi et al. (2023) further demonstrated the value of domain-specific VR training by developing an immersive module focused on rigging operations. Their training program allowed users to engage with virtual rigging equipment in realistic site scenarios, helping trainees safely practice complex procedures without exposure to real-world hazards.

While these studies underscore the growing sophistication of VR-based safety platforms, a persistent limitation remains: the lack of standardized methods to evaluate the effectiveness of immersive training programs. Getuli et al. (2023) proposed a semi-qualitative framework to evaluate immersive VR safety training by combining subjective user feedback; through post-experience surveys, with objective spatial tracking data visualized as heatmaps in a BIM environment. This dual approach offers a more comprehensive assessment of how trainees perceive and interact with virtual safety scenarios, paving the way for more evidence-based VR training protocols.

However, VR has limitations, including high resource requirements, time consumption, and an inability to fully replicate real-life conditions. To address the engagement gap in traditional safety inductions, Tepe et al. (2012) developed *"Playing 4 Safety,"* a desktop-based, walkthrough-style serious game built using Unity and 2D images. The game guided users through simulated construction scenarios, requiring them to identify hazards and select mitigation strategies using interactive decision-making and feedback mechanisms. While the visuals were contextually relevant and designed to support learning, the platform lacked the spherical field of view and spatial immersion that more advanced systems offer, as users interacted with scenes along a fixed linear path. To overcome these constraints, recent safety training platforms have adopted 360-degree panoramic images, which provide a low-cost, photo-realistic environment that enhances user engagement. Unlike 2D walkthroughs, these immersive images allow users to visually explore environments in all directions, closely mimicking the experience of being physically present on-site. This broader spatial awareness improves hazard identification and strengthens the connection between training content and real-world application. Eiris et al. (2020) compared VR and 360-degree panoramas, finding that panoramas provided a stronger sense of presence and reduced training time, although VR offered better clarity for hazard assessment. Further research was conducted by (Eiris et al., 2018) who developed a platform for safety training using 360-degree panoramas of real-life hazardous situations to enhance the hazard identification skills of workers. The platform using augmented 360-degree Panoramas of Reality (PARS) for safety training contained three sessions: 1) training, 2) assessment, and 3) feedback. Eiris et al. (2020) extended this work by using immersive storytelling to train workers on fall hazards, demonstrating that this method significantly reduced training time compared to traditional OSHA courses. Isingizwe et al. (2024) used 360-degree panoramas to develop virtual environments to simulate residential construction environments. This immersive VR experience with storytelling allows workers to interact with virtual hazards and receive personalized feedback. The findings show that this approach significantly improves behavioral and cognitive learning, aiding workers in better identifying fall hazards.

Hassanein & Hanna (2008) studied the implementation of safety practices in 35 of Egypt's large construction firms and compared the safety methods adopted in Egypt and USA. A questionnaire was structured to include more than 30 questions to collect data about safety implementation. EL-Deeb & Abasha (2020) collected data from three large-sized construction companies by conducting questionnaires with safety experts to identify the minimum safety requirements that should be adopted in Egyptian construction sites. These requirements include personal protective equipment, fall protection guardrail system, electrical protection, covering or barricading openings, and separating equipment passageways from personnel passageways in construction sites. (Elsebaei et al., 2020) summarized the major causes of accidents in construction projects in Egypt. It was concluded that the highest four causes were lack of housekeeping, lack of safety inspection by the government, lack of enforcement of safety regulations by organization and government, and lack of worker safety knowledge and safety education. Taha et al. (2024) analyzed the safety training content delivered to workers in some large-sized construction companies in Egypt concerning scaffolds and fall protection. It was concluded that construction sites in Egypt use traditional techniques and innovative methods like theatrical plays and hand-on training to enhance knowledge retention.

However, as previously mentioned, traditional techniques for safety training lack the immersive nature of virtual environments and result in low engagement of the trainees. The use of virtual environments offers an immersive alternative to traditional techniques and can allow trainees to face real-life hazards without having to deal with the associated risks. This approach aligns with Situated Learning Theory, which suggests that learning is most effective when it occurs within realistic and context-rich environments, enabling learners to acquire knowledge through participation in tasks that mirror actual work scenarios (Lave & Wenger, 1991). Additionally, by applying cognitive load theory which emphasizes the importance of reducing extraneous mental effort to optimize learning (Sweller, 1988). Accordingly, the developed game platforms minimize unnecessary complexity, ensuring that trainees can focus on critical hazard identification tasks without being overwhelmed.

The available literature underscores the importance of safety training and the potential of using virtual environments to enhance safety training effectiveness. Nevertheless, there is a notable gap in the research regarding the application of such methods within the Egyptian construction sector. Therefore, this study addresses this gap by developing a methodology for hazard identification using augmented 360-degree panoramic images. This methodology is integrated into a game-based platform to train participants in hazard assessment, from identifying hazards to implementing mitigation controls. By leveraging 360-degree panoramic environments, this approach will enhance engagement and retention of safety practices, while providing a safe and controlled setting for trainees to experience and react to realistic hazard scenarios.

3. RESEARCH METHODOLOGY

To overcome the limitations of the traditional safety training methods used in construction sites, this study proposes a hazard identification game platform to train participants in hazard assessment using augmented 360-degree panoramic images. As shown in Figure 1, the research methodology adopted is divided into three main steps: 1) conducting non-structured interviews with safety experts, 2) developing the game platform, and 3) evaluating the platform and statistically analyzing the collected feedback.

3.1 Interviews with Safety Experts

To identify the current safety practices in Egypt, unstructured interviews were conducted with five safety experts from two construction companies across three job sites. The first project involved the construction of 30 residential towers, each comprising 10 to 20 floors. The second project was a 300-bed hospital with five operational theaters. The third project entailed the development of a high-speed rail station, including a depot building.

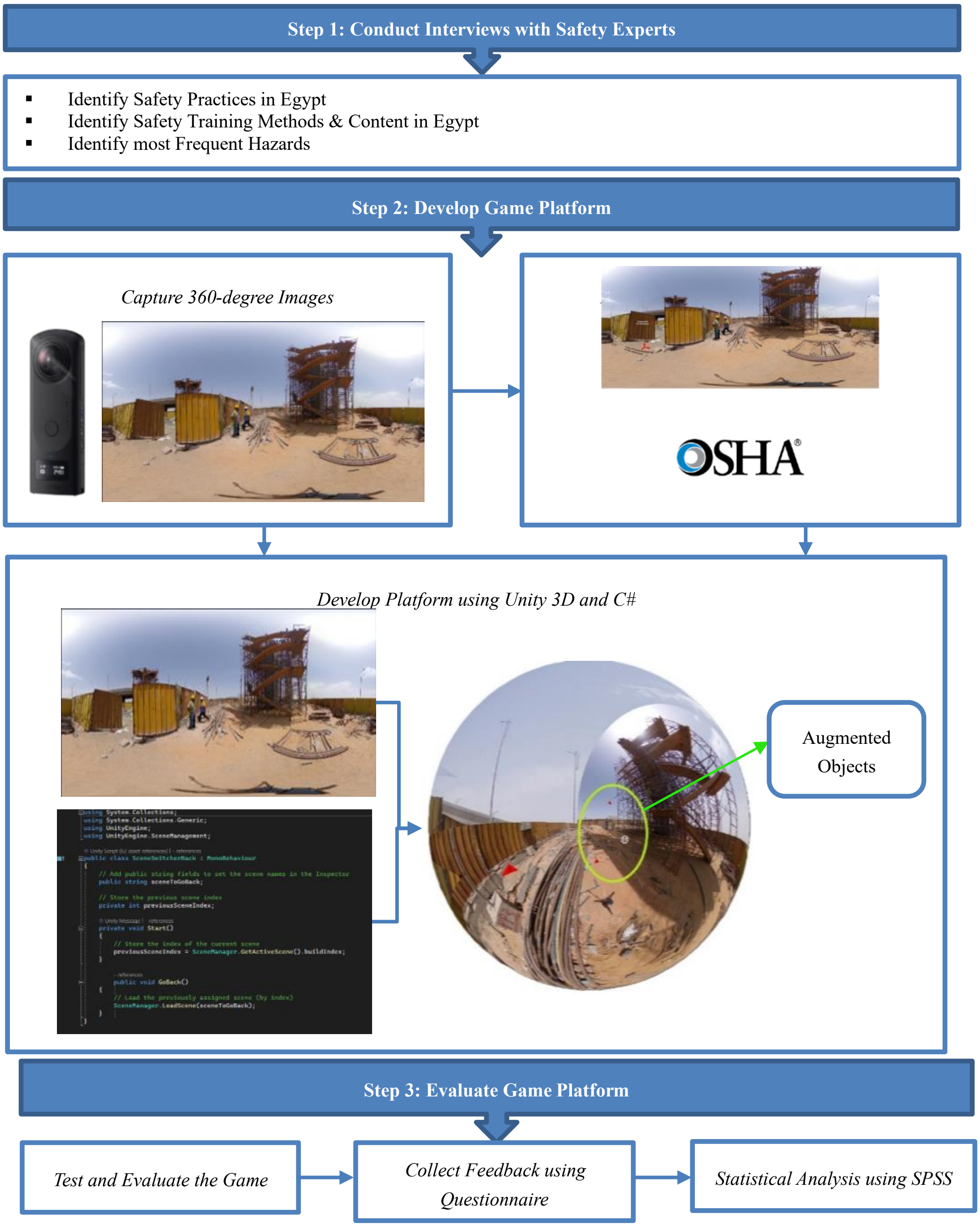

Figure 1: Research Methodology.

Nine areas were discussed in the interviews including site safety plan, safety team, safety training, causes of accidents, safety meetings, safety drills, site inspections, enforcement of the safety regulations, and records and documentation. The questions aimed to determine whether these practices were implemented on construction sites, how they were enforced, and the main causes of accidents in Egyptian construction sites. Additionally, the interviews explored the safety training methods used at the job sites to identify the current practices adopted in Egyptian construction. Five OSHA certified safety experts were interviewed in a non-structured way. Four interviewees had more than 20 years of experience while one had more than 10 years of experience.

3.2 Game Platform

The game was developed as shown in Figure 2 in three main steps: 1) capture 360-degree images from construction sites, 2) identify the hazards in the images with safety experts, and 3) design and implement the game. While capturing 360-degree panoramic images and hazard identification are established practices, in this study, they served as foundational components that enabled the integration of real jobsite conditions into a structured and interactive game-based learning environment. The novelty lies in how these elements were synthesized into a multi-stage training platform that embeds risk scoring, OSHA-aligned feedback, and immersive engagement tailored to local industry needs as illustrated in the upcoming sections.

A sphere-based panoramic walkthrough was developed using 360-degree images, with interactive elements embedded such as hazard logos, clickable hotspots, and navigational cues which were embedded using C# scripting. Each pre-identified hazard was mapped to its corresponding OSHA regulation and, where appropriate, linked to best practices adopted in the local context. through C# scripting. Pre-identified hazards were augmented with clickable objects that trigger pop-up panels referencing OSHA standards or control measures. A scoring system was implemented using the Analytical Hierarchy Process (AHP), allowing hazard scores to reflect severity and frequency. Each assessment scene included time limits and hazard counters, and user responses were recorded for post-assessment feedback. This structured game flow not only enhances user engagement but also reinforces safety knowledge through repetition and progressive learning.

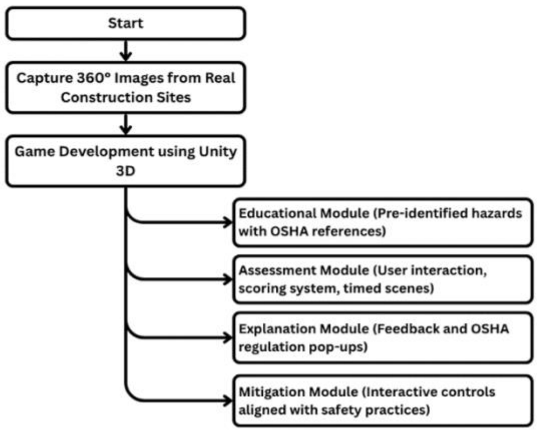

Figure 2: Development Workflow of the Game Platform.

3.2.1 Step 1: Capture 360-degree Images

Three construction sites were visited to capture 360-degree images for game development. A total of 107 360-degree images were taken using the Ricoh Theta Z1 360-degree camera. These images were captured with intentional overlaps and identifiable control points to facilitate the creation of a walkthrough, which will be utilized for developing the game environment.

3.2.2 Step 2: Hazard Identification in the Images

After the 360-degree panoramas were captured, meetings were conducted with two safety experts with more than 25 years of experience to identify the hazards in the images. In this study, OSHA standards were used as a reference framework, as they are widely adopted by mid- to large-sized construction companies in Egypt, particularly those with international affiliations or clients. The images were viewed using RICOH THETA application and the hazards were identified and recorded. In addition, the OSHA standards addressing the hazards were also identified for use in the game platform. The identified hazards and the OSHA standard regulations addressing each of the identified hazards that was used in the game platform are shown in Appendix A(OSHA, 2012, 2013, 2015, 2019a, 2019b, 2019c, 2020a, 2020b, 2020c, 2020d, 2020e). Table A.1lists the hazards and corresponding OSHA standard identified in the 360-images with two safety experts with more than 25 years of experience. Table A.2 references the hazards identified based on good safety practices adopted by the construction companies. Those safety practices are part of the safety policies enforced by the two safety experts in the job sites.

21 360-images were selected to be utilized in the game to create two walkthroughs to develop the game environment. Step 3 is described in the following section discussing the game design and implementation.

3.2.3 Step 3: Game Design and Implementation

Game Design

The game architecture was divided into three layers: application, software, and hardware. The application composed of the selected 360-degree panoramas. The available game engines with features to develop the game were explored to decide on the software to be used. Unity 3D was the selected game engine to develop the game due to the availability of references and documentation. Microsoft Visual Studio was also used to generate the associated C# scripts used in the game for interactivity. The game was developed to be played on a desktop or a laptop.

Game Implementation

The game is designed with four modules: Educational, Assessment, Explanation, and Mitigation Controls. Its primary purpose is to train users on the hazard assessment process, beginning with hazard identification and continuing through the necessary mitigation controls to reduce the impact of identified hazards. To illustrate the functionality of the platform, a demonstration video (Video available at: https://go.screenpal.com/watch/cTihI3nl33H) has been made available.

To provide a seamless walkthrough experience, C# scripts were employed, enabling users to navigate the environment and explore the scenes. Coding also facilitated built-in features such as interactive buttons, augmented objects activated by click actions, and sound effects for enhanced interactivity.

Educational Scene

Before participants begin the hazard identification process, they go through an educational scene developed to train them in hazard identification within a walkthrough crafted from captured images as shown in Figure 3. This scene includes 12 360-degree images with pre-identified hazards marked using hazard logos. C# scripts and Unity 3D built-in features generate pop-up panels triggered by clicks on these hazard logos, presenting relevant OSHA standards addressing each hazard. Hotspots allow users to switch between scenes effortlessly. Following the educational scene, participants enter the assessment scene to assess their hazard identification skills.

Figure 3: Screenshot of Educational Scene.

Assessment Scene

In the assessment scene, a tutorial explains how the assessment works, demonstrating the hazard identification process and allowing users to practice independently. The assessment consists of seven 360-degree images with augmented hidden objects. C# scripts ensure that clicking on these hidden objects reveals hazard logos. The scene also includes a counter for identified hazards, a time limit per scene based on the number of hazards, and an embedded hazard scoring system. Scenes automatically advance once the time expires or all pre-defined hazards are identified. At the end of the assessment, a scoreboard displays the user's score, the total number of identified hazards, and feedback on their hazard identification skills. Figure 4 and Figure 5 show a screenshot of the assessment scene and its explanation.

Figure 4: Explanation of Assessment Scene.

Figure 5: Screenshot of Assessment Scene.

Explanation Scene

The explanation scene then follows, utilizing the same seven 360-degree images from the assessment. Augmented objects trigger pop-up panels with appropriate OSHA standards when clicked as shown in Figure 6 for the pre-identified hazards explaining to the user the associated risks. Hotspots are also included to allow scene navigation.

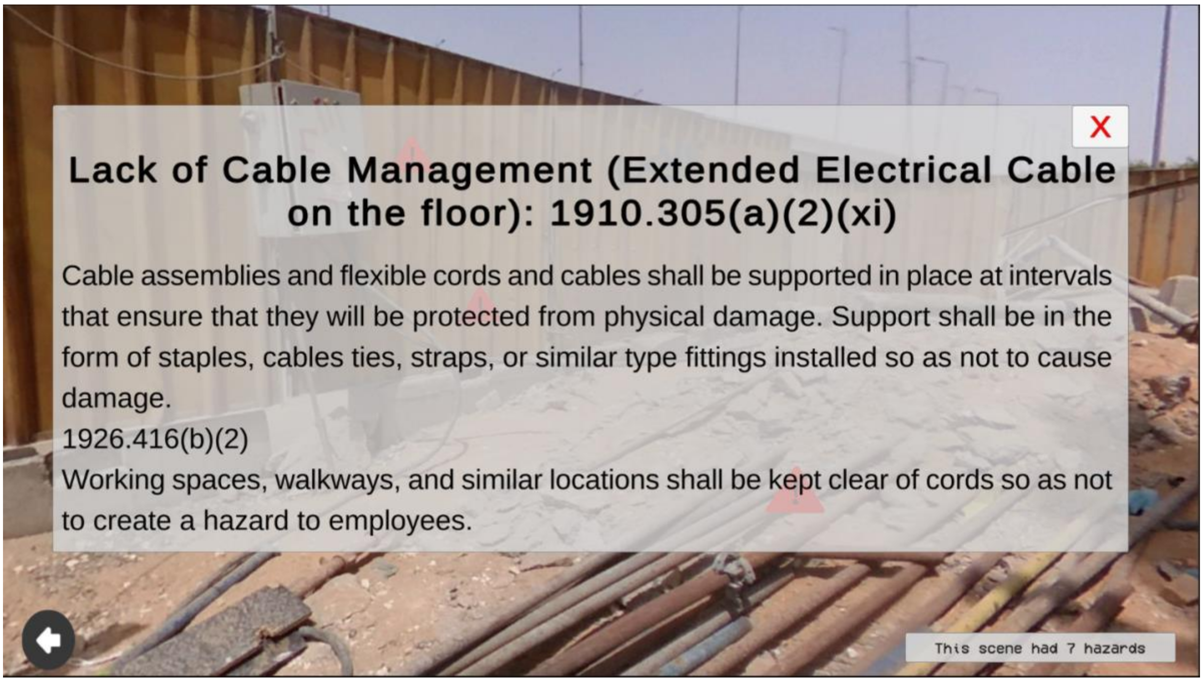

Figure 6: Screenshot of Explanation Scene.

Mitigation Control Scene

Finally, the mitigation control scene, as shown in Figure 7 uses the same seven 360-degree images, with augmented objects triggering pop-up panels that provide necessary mitigation control measures for each hazard, supplied by a safety expert with over 25 years of experience.

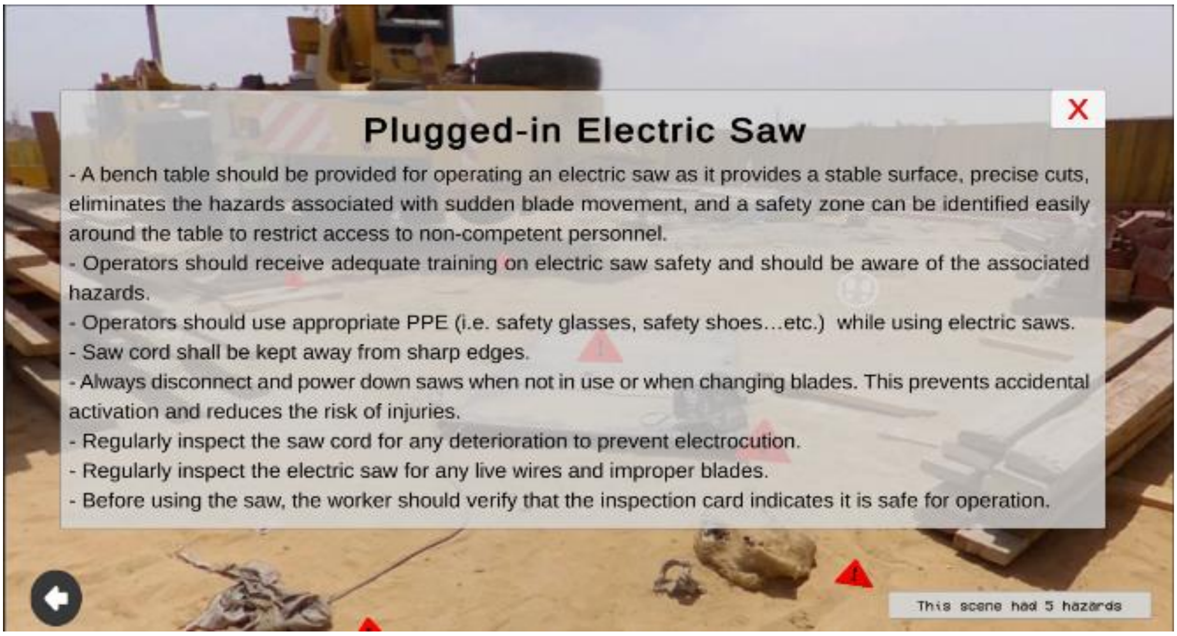

Figure 7: Screenshot of Mitigation Control Scene.

3.2.4 Hazard Identification Evaluation System

The evaluation system used in the game platform was developed through two stages. Firstly, Analytical Hierarchy Process (AHP) is conducted in three main steps: 1) develop a hierarchy for the problem, 2) create a pairwise comparison for each level of the matrices, 3) calculate the weights for each level as explained by (Saaty, 1980). This was implemented by first grouping the identified hazards into clusters which are identified per OSHA subparts as shown in Figure 8. Two structured interviews with more than 25 years of experience were asked to complete the pairwise comparison between the subparts and the identified hazards per subpart. The calculation steps for each level of the hierarchy are conducted using the following five steps.

While the Analytic Hierarchy Process (AHP) is a well-established decision-making method, its integration in this context adds a layer of depth by embedding expert judgment and regulatory priorities directly into the game's scoring system. Although users only see their overall scores, these scores are shaped by a structured evaluation of hazard severity, ensuring that training outcomes align with real-world safety priorities. This approach contrasts with traditional VR testing methods, which often focus solely on task completion or user immersion. By incorporating expert-informed weighting through AHP, the platform moves beyond generic assessment and subtly emphasizes the relative importance of different hazards, supporting a more focused and context-aware learning experience.

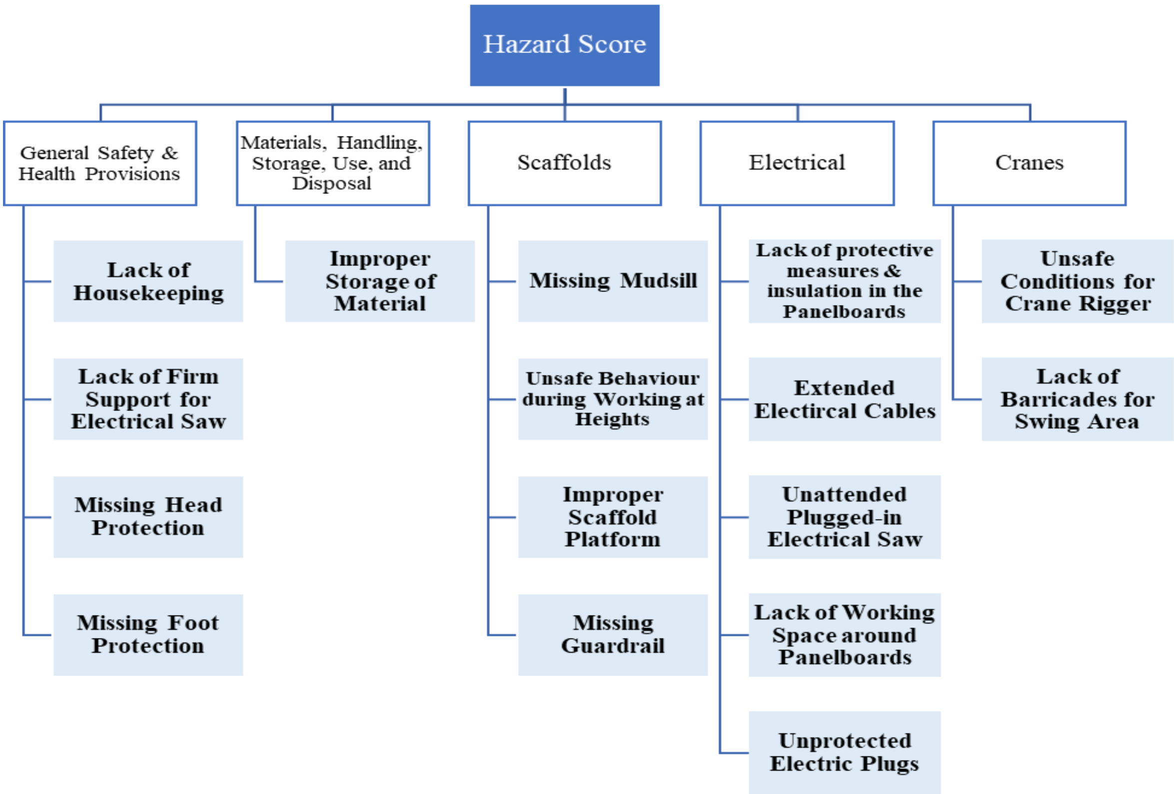

Figure 8: Hazard Score Hierarchy.

First: The pairwise comparison matrix A is developed based on the preferences collected from the experts which is put into a matrix as shown in Equation 1.

$$A = a_{ij} = \begin{matrix} & A_1 & A_2 & \cdots & A_n \\ A_1 & 1 & a_{12} & \cdots & a_{1n} \\ A_2 & 1/a_{12} & 1 & \cdots & a_{2n} \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ A_n & 1/a_{1n} & 1/a_{2n} & \cdots & 1 \end{matrix} \qquad (1)$$

where each element a_{ij} represents the relative importance of criterion i compared to criterion j.

Second: The pairwise comparison matrix A is then normalized by dividing each element a_{ij} by the sum of its column as shown in Equation 2. Then the normalized matrix is created as shown in Equation 3.

$$x_{ij} = \frac{a_{ij}}{\sum_{i=1}^{n} a_{ij}} \tag{2}$$

$$[X] = \begin{bmatrix} x_{11} & \cdots & x_{1n} \\ \vdots & \ddots & \vdots \\ x_{n1} & \cdots & x_{nn} \end{bmatrix} \tag{3}$$

Third: The largest eigenvalue of the matrix ($\lambda_{\max}$) is then calculated by first calculating the average of the rows w_i of the normalized matrix using Equation 4. Then the weighted sum S_i is calculated using Equation 5. $\lambda_{\max}$ is then calculated using Equation 6.

$$\mathrm{wi} = \frac{\sum_{\mathrm{j=1}}^{\mathrm{n}} \mathrm{xij}}{n} \tag{4}$$

$$S_i = \sum_{j=1}^{n} w_i a_{ij} \tag{5}$$

$$\lambda_{\max} = \frac{\sum_{j=1}^{n} \frac{S_i}{w_i}}{n} \tag{6}$$

Fourth: the consistency index (CI) is then calculated to check the consistency of the matrix using Equation 7.

$$CI = \frac{\lambda_{max} - n}{n - 1} \tag{7}$$

Fifth: the Consistency Ratio (CR) is then calculated to compare the CI against the Random Index (RI), which depends on the number of criteria using Equation 8. A CR of 0.10 or less is considered acceptable. If the CR is greater than 0.10, then the matrix is inconsistent, and the preferences of the safety experts should be revised.

$$CR = \frac{CI}{RI} \tag{8}$$

Where random index (RI) is the CI value of a randomly generated comparison matrix which depends on the matrix size (*n*).

By applying the above steps, the local and global weights of the identified hazards in the collected images were determined as shown in Table 1.

Secondly, the hazard score is then formulated based on the previously calculated global weights divided by the frequency of each hazard in the collected 360-degree images to determine the score of each hazard in the assessment scenes, using Equation 9 and Table 1.

$$Hazard\ Score\ (HSi) = \frac{Global\ Weight\ (Wi)}{Frequency\ (Fi)} \tag{9}$$

Where HS_i is the hazard score for the corresponding hazard, F_i is the frequency of occurrences of the corresponding hazard in the scenes, and the W_i is the previously calculated global weight for the corresponding hazard.

Once the hazard score was calculated, the frequency of each hazard in the seven 360-degree images in the assessment scenes was identified to calculate the hazard score for each hazard in the scene to be added in Unity 3D. The calculated hazard score is identified for each of the pre-identified hazards in the assessment scenes and the total of the hazard score is 100% which is retrieved in the scoreboard.

Table 1: Local and Global Weights of Hazards.

Criteria	Criteria Weight (%)	Sub-criteria	Local Weight (%)	Global Weights (%)
Subpart C - General Safety and Health Provisions	9.00	Lack of Housekeeping	21.00	1.89
		Lack of Firm support for Electric Saw	8.80	0.79
		Missing Head Protection	35.10	3.16
		Missing Foot Protection	35.10	3.16
Subpart H - Materials Handling, Storage, Use, and Disposal	5.50	Improper storage of material	100.00	5.50
Subpart L – Scaffolds	29.80	Missing mudsill	8.26	2.46
		Unsafe Behavior during Working at Heights	22.20	6.62
		Improper scaffold platform	30.17	8.99
		Missing Guardrail	39.37	11.73
Subpart K – Electrical	29.80	Lack of protective measures & insulation in the Panelboards	21.19	6.32
		Extended Electrical Cables	23.59	7.03
		Unattended Plugged-in Electric Saw	15.38	4.58
		Lack of Working Space around Panelboards	22.61	6.74
		Unprotected Electric Plugs	17.23	5.13
Subpart CC - Cranes & Derricks	25.90	Unsafe Conditions for Crane Rigger	50.00	12.95
		Lack of Barricades for the Swing Area	50.00	12.95

The participants then played the hazard identification game and their scores were collected. Their post-game feedback was then collected using a questionnaire to collect their feedback. The questionnaire consisted of 22 questions and was divided into two parts for pre-game evaluation and post-game evaluation, as shown in Table 2. The first five questions in the questionnaire were to collect the demographic data and the current safety background of the participants; including but not limited to, years of experience, job position, and certifications. Questions six through 12 were Likert scale questions, with a scale of one to five, which focused on the user interface of the game. Questions 13 to 21 were also Likert scale questions, with a scale of one to five, which focused on the user's game experience. Lastly, question 22 was an open ended question to collect any further ideas from the users. The questionnaires were filled-in by the 30 construction practitioners who played the game, as well as, their scores and the number of hazards the users identified to be analyzed using statistical tests as will be explained in the following sections.

The feedback and scores are then analyzed using SPSS to test the hypothesis that the safety training game enhances safety knowledge retention. Additionally, this analysis will assess whether the game can serve as an engaging alternative to traditional safety training methods. The findings will guide recommendations for further development and implementation of the game to meet user needs effectively. The analysis is divided into two parts as follows.

Part 1: Testing Normality and Variance of Scores

To combine feedback from both construction sites for further analysis, the means and variances of the two groups will be compared. First, a normality test will be conducted to determine whether the data distribution supports the use of parametric or non-parametric tests. Based on this result, appropriate statistical methods will be applied to assess whether the groups can be pooled together for comprehensive evaluation.

Normality Test

According to (Mishra et al., 2019), for a sample size of less than 50, Shaprio–Wilk test is the most adequate test to determine the normality of the collected data. The null hypothesis of the Shapiro-Wilk test (Shapiro & Wilk, 1965) is that the samples are normally distributed. If the p-value is less than 0.05, the null hypothesis is rejected, indicating that the sample is not normally distributed. This was conducted to determine whether a parametric test like Two-tailed T-Test is to be used (data normally distributed) or a non-parametric test like Wilcoxon Signed Rank test (data is not normally distributed) to compare between two groups. The following Equation 10 was used to assess the normality of the scores collected from the 30 participants.

Table 2: Questions from Questionnaire.

Topic	***Question***	
Demographics	**Q1.**	How many years of experience do you have in the construction industry?
	Q2.	Current position/Occupation
	Q3.	Do you have any certification from the following?
	Q4.	On a scale of 1 – 5 (where 1 is not familiar and 5 is extremely familiar), can you rate how familiar you are with the following topics? • OSHA Regulations, • Virtual Reality, • 360-degree Panoramic Images
	Q5.	Have you taken any safety training in the construction projects you attended?
User Interface	**Q6.**	On a scale of 1 – 5 (where 1 is very unclear and 5 is very clear), how would you rate the clarity of the 360-panorama images?
	Q7.	On a scale of 1 – 5 (where 1 is very difficult and 5 is very easy), how easy did you find it to explore the different areas in the scene?
	Q8.	On a scale of 1 – 5 (where 1 is not visible and 5 is extremely visible), were the augmented hazard logos visible?
	Q9.	On a scale of 1 – 5 (where 1 is not distinguishable and 5 is extremely distinguishable), were the augmented hazard logos distinguishable from the surroundings?
	Q10.	On a scale of 1 – 5 (where 1 is not responsive and 5 is extremely responsive), can you rate how responsive the interface was?
	Q11.	On a scale of 1 – 5 (where 1 is very hard and 5 is very easy), how easy was it to identify the hazards in the assessment scene?
	Q12.	On a scale of 1 – 5 (where 1 is extremely inadequate and 5 is extremely adequate), how adequate was the time assigned to each 360-panorama image in the assessment scene?
User's Game Experience	**Q13.**	On a scale of 1-5 (where 1 is not effective and 5 is very effective), how effective is the game as a learning platform compared to your previous safety training experiences?
	Q14.	On a scale of 1-5 (where 1 is not engaging at all and 5 is very engaging), how engaging did you find the game?
	Q15.	On a scale of 1-5 (where 1 is not consistent at all and 5 is very consistent), to what extent was your "in-game experience" consistent with your real-life experiences?
	Q16.	On a scale of 1 – 5 (where 1 is not useful at all and 5 is very useful), how useful was the information provided in the game's educational scenes for your safety knowledge?
	Q17.	On a scale of 1-5 (where 1 is strongly disagree and 5 is strongly agree), would you agree with the following statement: *"The use of 360-panorama images is useful as it provides an immersive tour for the trainee without facing the associated risks with real-life hazards."*
	Q18.	On a scale of 1-5 (where 1 is not at all and 5 is extremely), how much do you think the game helped you improve your hazard identification skills?
	Q19.	On a scale of 1-5 (where 1 is not at all confident and 5 is very confident), how confident do you feel about applying what you learned in real-life situations?
	Q20.	On a scale of 1-5 (where 1 is not interested at all and 5 is very interested), would you be interested in using game-based learning to learn about construction?
	Q21.	On a scale of 1 - 5 (where 1 is not all likely and 5 is extremely likely), how would you recommend this game as a training tool for on-site safety training?
Further Ideas from Users	**Q22.**	Is there anything else you'd like to share or any ideas you have to improve the game?

$$W = \frac{\left(\sum_{i=1}^{n} a_i x_i\right)^2}{\sum_{i=1}^{n}(x_i - \bar{x})^2} \tag{10}$$

Where:

- x_i represents the i[th] order statistic (i.e., the i[th] smallest value in the sample).
- $\bar{x}$ is the sample mean.
- a_i are constants calculated based on the means, variances, and covariances of the order statistics of a standard normal distribution.

Comparing Variances and Means of Both Groups

To assess the equality of variances between the two groups, F-Levene's Test (Cleves, 1996) is applied. The null hypothesis of F-Levene's test is that the variances are equal. If the p-value is less than 0.05, the null hypothesis is rejected, indicating that the variances are significantly different. Equation 11 was used to conduct F-Levene's Test to compare the variances of both groups.

$$W = \frac{(N-k)}{(k-1)} \cdot \frac{\sum_{i=1}^{k} N_i (Z_{i.} - Z_{..})^2}{\sum_{i=1}^{k} \sum_{j=1}^{N_i} (Z_{ij} - Z_{i.})^2} \tag{11}$$

Where:

- N is the total number of observations.
- k is the number of groups.
- N_i is the number of observations in the ith group.
- Z_{ij} is the value of the jth observation in the ith group.
- Z_i is the mean of the ith group.

Comparison of Means

If the scores are normally distributed, Two-tailed T-test [(Bower, 2001), (Cressie and Whitford, 1986)] will be used to compare the means of both groups. The null hypothesis for Two-tailed T-test is that there is no difference between the means of both groups. If the p-value is less than 0.05, then the null hypothesis is rejected, indicating that there is a significant difference between the means of both groups. Two-tailed T-test was calculated using Equations 12 and 13.

$$t = \frac{\bar{x}_1 - \bar{x}_2}{s_p \sqrt{\frac{1}{n_1} + \frac{1}{n_2}}} \tag{12}$$

Where:

- $\bar{x}_1$ and $\bar{x}_2$ are the sample means,
- n_1 and n_2 are the sample sizes,
- s_p is the pooled standard deviation, calculated as:

$$s_p = \sqrt{\frac{(n_1 - 1)s_1^2 + (n_2 - 1)s_2^2}{n_1 + n_2 - 2}} \tag{13}$$

Where:

- S_1^2 and S_2^2 are the sample variances.

If the data is not normally distributed, Wilcoxon Signed Rank test [(Wilcoxon, 1945), (Rey & Neuhäuser, 2011)] will be used to compare the participants' responses to the population median of 3, assuming neutral pre-game responses. The null hypothesis of Wilcoxon Signed Rank test is that median of differences between the population median of 3 and the participants' responses equals 0. Equation 14 is used to calculate the test statistic (W).

$$W = min(W^+, W^-) \tag{14}$$

Where W^+ and W^- are the sums of positive and negative ranks.

Part 2: Analyzing Participants' Responses

The second part of the analysis is to analyze the responses to questions six to 21 to determine if they align with the research hypothesis using Shapiro-Wilk Test. A normality test was conducted on the Likert scale responses to decide whether to use a parametric test (like the Two-tailed T-test) or a non-parametric test (like the Wilcoxon Signed Rank test). Prior to performing the statistical analysis, the reliability of the responses was first tested to check the internal consistency reliability of the responses to the Likert scale questions. This can be calculated using Cronbach's Alpha (Al Zarooni et al., 2022; Soh et al., 2020) which measures the internal consistency of the data collected. The alpha value calculated using Equation 15 is then compared to the Table 3 to interpret the internal consistency of the results.

$$\alpha = \frac{N \cdot \bar{c}}{\bar{v} + (N-1) \cdot \bar{c}} \tag{15}$$

Where:

- N is the number of items,
- $\bar{c}$ is the average inter-item covariance,
- $\bar{v}$ is the average variance of each item.

Table 3: Cronbach's Alpha Interpretation.

Test Type	**Sig. (p-value)**
$0.9 \leq \alpha$	Excellent
$0.8 \leq \alpha < 0.9$	Good
$0.7 \leq \alpha < 0.8$	Acceptable
$0.6 \leq \alpha < 0.7$	Questionable
$0.5 \leq \alpha < 0.6$	Poor
$\alpha < 0.5$	Unacceptable

Based on the distribution of the participant's responses according to Shapiro-Wilk Test, the responses are further analyzed using a parametric test or a non-parametric test, as previously described. The following sections will summarize the results of the statistical analysis.

4. RESULTS & DISCUSSION

4.1 Safety Experts Interviews' Results

According to the interviews, it was found that there was a dedicated safety department in the companies and a site safety team was selected for each project. The interviewees monitored the implementation of the project's safety plan, which imposes the company's safety procedures.

Furthermore, the companies, represented by the interviewees, used different safety training methods at the job sites, such as delivering presentations, videos, and mock-ups to explain hazards' impact to trainees and performing theatrical plays to demonstrate the consequences of unsafe behaviors and potential threats. It was also found that the companies provided adequate PPEs for each job to all on-site workers, and penalties were imposed if not used. It was also mentioned that drills were conducted on-site concerning fire to ensure the adequacy of the emergency plan, first-aid, and all types of hazards periodically. As well as recording and documenting all accidents, including first-aid cases, near-misses, and work permits for all on-site jobs. Moreover, the companies imposed penalties for not abiding by the safety procedures set by the safety plan and benefits to encourage good safety behavior on-site. Safety experts also identified that job site accidents in Egypt often result from working at heights, falling objects, and lack of housekeeping.

The interviews revealed that traditional safety training methods in Egyptian construction sites are unengaging and may not effectively mitigate risks such as working at heights and falling objects.

As a result, this research aims to develop a game platform utilizing augmented 360-degree panoramic images to enhance safety training, as detailed in the following sections. The images for the game platform were collected from a transportation project involving pier construction, in which the increased risk of hazards related to heights, falling objects, electrical work, and lack of housekeeping was highlighted.

4.2 Participants Demographics and Safety Background

Before testing the safety training game, the participants responded to questions one to five of the questionnaire. The results revealed that 79% of the participants had more than 5 years of experience in construction and 70% of the participants were OSHA and National Examination Board in Occupational Safety and Health (NEBOSH) certified. The sample reflected a range of roles, including managers, safety personnel (43% of the sample), engineers, foremen, and workers. A total of 80% were familiar with OSHA regulations, 77% were familiar with 360-degree panoramas, and 73% of them had previous experience with VR. All of the participants (100%) had previously attended safety training programs at the job sites. 73% of the participants have received safety training only using traditional training methods; which include lectures, workshops, videos, mock-ups/demos, drills, peer-to-peer training, scenario-based learning; and 27% of the participants also received safety training using VR.

4.3 Hazard Score Analysis

The game was then tested on 30 construction practitioners from two construction sites and the scores of the participants have been collected to be statistically analyzed. This was conducted to determine whether the data collected from both sites can be pooled together or not through comparing means and variances of both groups.

4.3.1 Shapiro-Wilk Test (Normality)

The scores collected from participants at both construction sites were tested for normality using the Shapiro-Wilk test in SPSS (IBM Corp., 2022). With a p-value of 0.071, which is greater than the standard alpha level of 0.05, we fail to reject the null hypothesis of normality. This indicates that the scores are normally distributed.

4.3.2 F-Levene's Test (Equality of Variances)

To determine the equality of variances, F-Levene's test was calculated for the collected scores. As shown in Table 5, the p-value was calculated for F-Levene's Test based on mean, median, median and with adjusted df, or trimmed mean using SPSS. P-value was greater than 0.05, as a result, it can be concluded that the variances between the two construction sites are not significantly different. Thus, it can be concluded that both samples have equal variances and can be pooled together for further analysis.

Table 4: F-Levene's Test Results.

Test Type	Sig. (p-value)
Based on Mean	0.483
Based on Median	0.461
Based on Median and with adjusted df	0.461
Based on Trimmed Mean	0.491

4.3.3 Two Tailed T-test (Comparing Means)

A two-tailed T-test was conducted to compare the means of the scores from both construction sites. Since the p-value from F-Levene's test indicated equal variances, the two-tailed p-value was calculated to be 0.194, which is greater than 0.05. This suggests there is no significant difference between the means of the two groups.

Consequently, the data from both construction sites were pooled together for further analysis, as explained in the following sections.

4.4 Analyzing Participants' Responses

In the following sections, the participants' responses to the questions six to 21 will be further analyzed. Firstly, the responses to questions about the user interface and user's game experience were analyzed using Cronbach's alpha to determine whether the results collected were reliable or not. Cronbach's Alpha was 0.840066 and 0.84244, which lies between 0.8 and 0.9, accordingly the reliability is good and further analysis can be conducted.

The participants' responses to questions six to 21 were first tested for normality using Shapiro-Wilk Test and the p-value for the responses to all questions is less than 0.001 which is less than 0.05. Accordingly, it can be concluded that the null hypothesis is rejected, and the data do not follow a normal distribution.

Accordingly, Wilcoxon Signed Rank test was conducted on the participants' responses to compare their responses to the population median of 3, assuming neutral pre-game responses. The null hypothesis of this test is that median of differences between the population median of 3 and the participants' responses equals 0.

4.5 User Interface Evaluation

This section of the analysis focused on analyzing the responses of the participants to questions six to 12 using Wilcoxon Sign Rank Test, which aimed at collecting their feedback on the game's user interface.

4.5.1 Clarity of 360-degree Panoramic Images

To evaluate the clarity of the 360-degree images, the responses to question six were collected from the participants and thoroughly analyzed. This analysis aimed to gather comprehensive feedback on the visual quality and clarity of the images. The p-value of the responses was less than 0.001, which is below the 0.05 significance level. As a result, the null hypothesis was rejected, and it was concluded that there were significant differences between the participants' responses and the population median of 3. As shown in Figure 9, 97% of participants responded with "4-Clear" or "5-Very Clear," indicating that the 360-degree images used in the game were perceived as clear.

4.5.2 Ease of Exploration of the Scenes

The ease of exploring the scenes was assessed by analyzing the participants' responses to question seven. The p-value of the responses was less than 0.001, which is below the 0.05 significance level. Consequently, the null hypothesis was rejected, indicating significant differences between the participants' responses and the population median of 3. As shown in Figure 9, all 30 participants (100%) responded with '4-Easy' and '5-Very Easy,' suggesting that the participants did not find the exploration of the scenes difficult.

4.5.3 Visibility of Hazard Logos

The visibility of the hazard logos in the game environment was also assessed by analyzing the responses to questions eight and nine. The p-value of the responses was less than 0.001, which is below the 0.05 significance level. Consequently, the null hypothesis was rejected, indicating significant differences between the participants' responses and the population median of 3. As per Figure 9, 97% of the participants responded with "4-Visible/Distinguishable" and "5-Extremely Visible/Extremely Distinguishable" confirming that the hazard logos were clear and distinguishable from the surroundings.

4.5.4 Responsiveness of the Interface

In addition, the responsiveness of the game interface was meticulously assessed by analyzing the responses to question ten. This question aimed to gather detailed feedback on how effectively and promptly the interface responded when participants clicked to navigate through the scenes and identify hazards. The p-value of the responses was less than 0.001, which is below the 0.05 significance level. Consequently, the null hypothesis was rejected, indicating significant differences between the participants' responses and the population median of 3. As per Figure 9, 20% of the participants responded with "3 - Neutral", while the remaining 80% responded with "4-Responsive" and "5- Extremely Responsive". As a result, we can conclude that the interface was responsive, and the participants had no issues while playing the game.

4.5.5 Ease of Hazard Identification

The responses to question 11 were analyzed to determine the ease of hazard identification in the game. The p-value of the responses was less than 0.001, which is below the 0.05 significance level. Consequently, the null hypothesis was rejected, indicating significant differences between the participants' responses and the population median of 3. As per Figure 9, 100% of the participants responded with "4-Easy" and "5- Very Easy". As a result, we can conclude that the hazard identification process was easy for the users.

4.5.6 Time Allocation for Hazard Identification

The allocated time for hazard identification process was assessed by analyzing the responses to question 12. The p-value of the responses was less than 0.001, which is below the 0.05 significance level. Consequently, the null hypothesis was rejected, indicating significant differences between the participants' responses and the population median of 3. As per Figure 9, 20% responded with "3 - Neutral", while the remaining 80% responded with "4- Adequate" and "5- Extremely Adequate", confirming that the allocated time for hazard identification was suitable for the users to identify the hazards in the scenes.

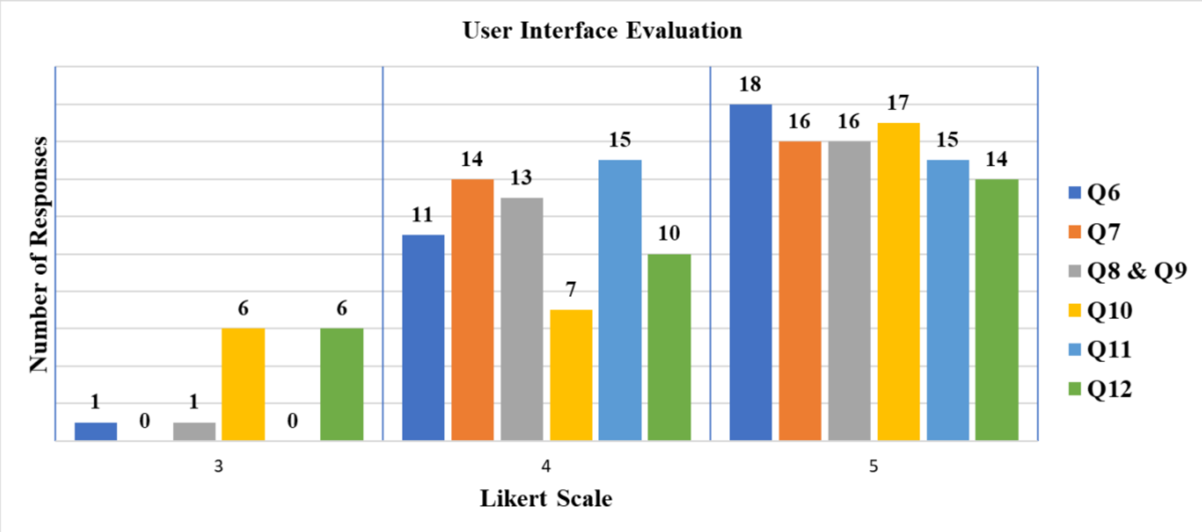

Figure 9: Statistical Analysis Results for User Interface Questions.

4.6 User's Game Experience Evaluation

This section of the analysis focused on analyzing the responses of the participants to questions 13 to 21 using Wilcoxon Sign Rank Test, which aimed at collecting their feedback on their game experience. It also focused on collecting their feedback on whether the developed game platform can offer an immersive safety training tool as an alternative to traditional safety training methods.

4.6.1 Effectiveness of Game as a Learning Platform

The effectiveness of the game as a learning platform was first assessed by analyzing the responses to question 13. The p-value of the responses was less than 0.001, which is below the 0.05 significance level. Consequently, the null hypothesis was rejected, indicating significant differences between the participants' responses and the population median of 3. As per Figrue 10, 100% of the participants "responded with "4-Effective" and "5- Very Effective". As a result, we can conclude that the game platform can be an effective learning platform to be used for educational purposes.

4.6.2 Engagement of the User with the Game

The engagement of the user with the game was assessed by analyzing the responses to question 14. The p-value was less than 0.001 which is less than 0.05, as a result, the null hypothesis was rejected, and it was concluded that there were significant differences between the participants' responses and the population median of 3. As per Figrue 10, 3% responded with "3 - Neutral", while the remaining 97% responded with "4-Engaging" and "5-Very Engaging". As a result, we can conclude that the users found the game to be engaging.

4.6.3 Consistency of Game Experience with Real-life

The responses to question 15 were analyzed to identify the consistency between the user's experience and real-life. The p-value of the responses was less than 0.001, which is below the 0.05 significance level. Consequently, the null hypothesis was rejected, indicating significant differences between the participants' responses and the population median of 3. As per Figure 10, 3% responded with "3 - Neutral", while the remaining 97% responded with “4-Consistent” and “5-Very Consistent”. As a result, we can conclude that the user experience was consistent with their real-life experiences as the 360-degree images provide the users with a photo-realistic environment.

4.6.4 Usefulness of Information in the Educational Scenes

The usefulness of the information provided in the educational scenes was assessed by analyzing the responses to question 16. The p-value of the responses was less than 0.001, which is below the 0.05 significance level. Consequently, the null hypothesis was rejected, indicating significant differences between the participants’ responses and the population median of 3. As per Figure 10, 3% responded with "3 - Neutral", while the remaining 97% responded with “4-Useful” and “5-Very Useful”. As a result, we can conclude that the information provided in the educational scenes is very useful to enhance the user’s safety knowledge.

4.6.5 Immersive Tour Using 360-degree Panoramic Images

The feedback of the users to question 17 was assessed to evaluate whether the developed game platform provides an immersive tour for safety training without facing the risks of the real-life hazards. The p-value of the responses was less than 0.001, which is below the 0.05 significance level. Consequently, the null hypothesis was rejected, indicating significant differences between the participants’ responses and the population median of 3. As per Figure 10, 3% responded with "3 - Neutral", while the remaining 97% responded with “4-Useful” and “5-Very Useful”. This indicated the effectiveness of the panoramic images in providing a risk-free learning environment.

4.6.6 Hazard Identification Skills Improvement

One of the main purposes of the developed game is to improve the hazard identification skills of the users. Therefore, the responses to question 18 were assessed to collect feedback from the participants on how the game can improve those skills. The p-value of the responses was less than 0.001, which is below the 0.05 significance level. Consequently, the null hypothesis was rejected, indicating significant differences between the participants’ responses and the population median of 3. As per Figure 10, 3% responded with "3 - Neutral", while the remaining 97% responded with “4-Somewhat” and “5-Extremely”. This indicates the game’s effectiveness in improving these skills.

4.6.7 Application of Gained Knowledge in Real-life Situations

Added to that, it was important to determine whether the gained safety knowledge could be applied or not in real-life situations. Therefore, the responses to question 19 were assessed to collect the feedback from the participants. The p-value of the responses was less than 0.001, which is below the 0.05 significance level. Consequently, the null hypothesis was rejected, indicating significant differences between the participants’ responses and the population median of 3. As per Figure 10, 7% responded with "3 - Neutral", while the remaining 93% responded with “4-Confident” and “5-Very Confident”. As a result, we can conclude that the users are confident about applying the gained knowledge from the game in real-life situations.

The collected responses to questions 20 and 21 were analyzed to determine whether game-based learning would be beneficial for education about construction, as well as to assess if the developed game platform can be used as an on-site safety training tool based on the participants' experiences.

4.6.8 Use of Game-based Learning as an Educational Platform

The p-value of the responses to question 20 was less than 0.001, which is below the 0.05 significance level. Consequently, the null hypothesis was rejected, indicating significant differences between the participants’ responses and the population median of 3. As per Figure 10, 3% responded with "3 - Neutral", while the remaining 97% responded with “4-Likely” and “5-Extremely Likely”. As a result, we can conclude that the users would recommend using game-based platforms for educational purposes.

4.6.9 Recommendation of the Game as an On-Site Safety Training Tool

The p-value of the responses to question 21 was less than 0.001, which is below the 0.05 significance level. Consequently, the null hypothesis was rejected, indicating significant differences between the participants’ responses and the population median of 3. As per Figure 10, the chart shows that there is a positive difference between the participants’ responses and the population median of 3. Only one participant (3%) responded with "3 - Neutral", while the remaining 29 participants (97%) responded with “4-Likely” and “5-Extremely Likely”, affirming its value as a safety training tool.

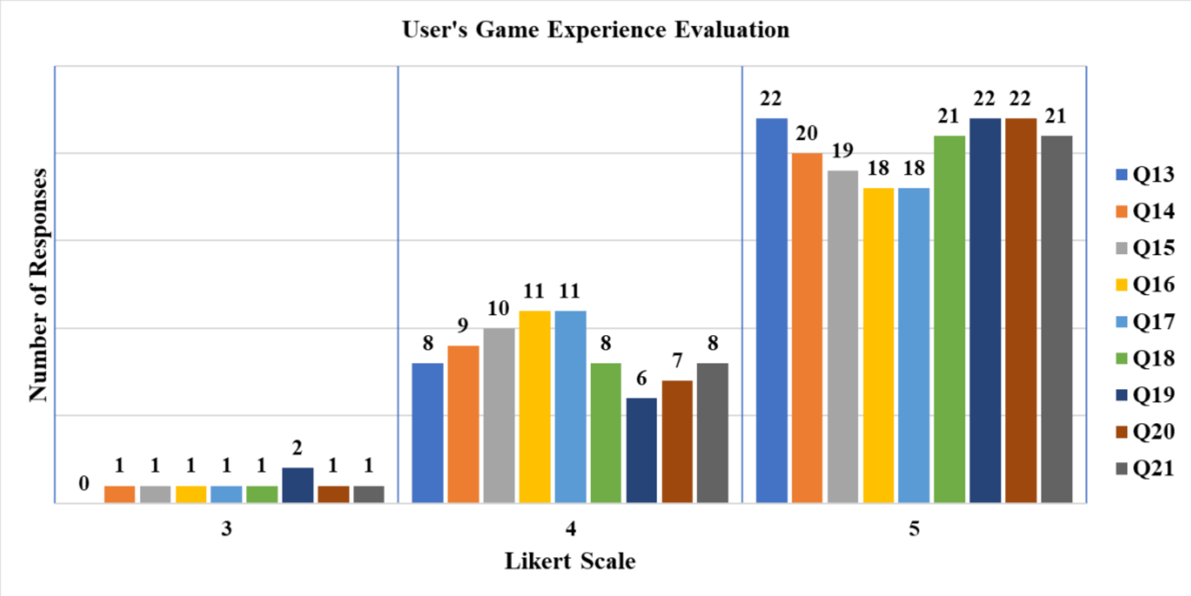

Figure 10: Statistical Analysis Results for User's Game Experience Evaluation.

Based on the previous sections, it was found that the participants had a positive feedback on the platform's user interface and their game experience. It can be concluded that the game provided an immersive and realistic environment suitable for safety training. It was highly recommended by the users as an effective educational platform and alternative to traditional safety training methods.

5. CONCLUSION

Safety training is important to enhance the safety knowledge among the construction workers. However, the traditional safety training methods are uninteresting and not engaging to the trainees. This research adopted a three-step methodology involving (1) identifying current safety practices and common hazards in Egypt through unstructured interviews with safety experts, (2) developing an interactive game platform using augmented 360-degree panoramic images captured from real construction sites, and (3) evaluating the platform's effectiveness through statistical analysis of user feedback and performance data. Unstructured interviews conducted with safety experts in Egypt indicated that traditional safety training methods can be ineffective and not engaging. Furthermore, it was determined that the main causes of job site accidents in Egypt are working at heights, falling objects, and lack of housekeeping. Consequently, this research focused on developing a safety training game to serve as an effective, engaging, and immersive training tool. The game platform was divided into four modules: Educational, Assessment, Explanation, and Mitigation Controls. The game was tested by 30 construction practitioners and evaluated using a questionnaire. Participant's responses were statistically analyzed using the Wilcoxon Signed Rank Test which revealed significant positive differences between participants' responses and the neutral population median. Participants consistently rated the game's features, such as the clarity of 360-degree panoramic images, ease of exploration, and visibility of hazard logos, as highly effective. Furthermore, the platform's responsiveness, adequacy of allocated time, and ease of hazard identification were well-received, with participants expressing no significant difficulties in these areas. The game was also found to provide a realistic and photo-immersive environment, with participants acknowledging its consistency with real-life scenarios. This highlights the platform's ability to simulate real-world conditions in a risk-free setting, making it a suitable alternative to traditional safety training methods. Additionally, the educational content embedded within the game significantly improved participants' hazard identification skills and their confidence in applying this knowledge in real-life situations. Participants expressed high levels of engagement with the game and overwhelmingly endorsed its effectiveness as a learning platform. Nearly all participants indicated a strong likelihood of recommending the game as a viable on-site safety training tool. This endorsement underscores the potential of game-based learning to enhance traditional safety training practices, particularly in the construction industry.

This research presents the development of an immersive safety training platform customized for the Egyptian construction industry, along with a performance scoring system designed using the Analytic Hierarchy Process (AHP) to assess hazard identification skills. The platform was evaluated through structured testing with 30 construction practitioners from ongoing Egyptian construction projects, ensuring that the feedback reflects real-world, context-specific insights.

Building on this foundation, the developed safety training game effectively combines immersive technology with educational content to provide an impactful training experience. By addressing the challenges associated with traditional methods, this game offers an approach to improving safety knowledge, hazard identification skills, and user engagement. These findings support the use of such game-based platforms as a valuable component of safety training programs across industries. This study had some limitations. This study focused on the Egyptian construction industry to address a context-specific gap in safety training practices and regulatory alignment. While the platform was developed and validated with input from local OSHA-certified safety experts, their perspectives may not fully reflect global best practices or innovations emerging from regions such as America, Europe, or Asia. As such, the findings are most directly applicable to Egypt and other developing countries with similar safety challenges and resource constraints, where traditional training methods remain predominant. Future research should consider involving international experts or conducting cross-cultural validations to broaden the applicability and enhance the global relevance of the developed methodology. This foundational framework; leveraging augmented 360-degree panoramic imagery for immersive, low-cost training; demonstrates adaptable potential across diverse construction safety contexts, particularly in settings where traditional methods are still dominant. Additionally, the participants who evaluated the game were from the same large-sized company. To diversify perspectives, future evaluations can involve participants from other large-sized companies with varied safety backgrounds. Additionally, the game scenarios could be expanded to address hazards such as working in confined spaces or those associated with heavy equipment. Furthermore, automating the hazard labeling process using AI-driven approaches, such as computer vision techniques trained on annotated 360-degree images, could significantly enhance the scalability, efficiency, and novelty of the platform. Incorporating such capabilities may reduce expert dependency and allow for more dynamic updating of training content across varied job site conditions. Another limitation is the absence of a control group or baseline comparison. While the platform was found to be effective through post-intervention analysis, the study did not assess participants' hazard recognition performance before training or compare results against a traditional training control group. Future studies could adopt a comparative experimental design; for example, measuring hazard identification performance before and after exposure to the game, or comparing outcomes between groups trained with and without 360-degree images. These approaches would provide more robust insights into the platform's impact on cognitive learning and skill acquisition. Future research could also incorporate eye-tracking technology to assess participants' cognitive skills during the hazard identification process.

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APPENDIX A: IDENTIFIED HAZARDS IN 360-DEGREE IMAGES

Table A.1: Hazards and corresponding OSHA standard.

Identified Hazards	OSHA Standard Regulation	OSHA Standard Interpretation
Lack of Housekeeping	1926.25(a)	During the course of construction, alteration, or repairs, form and scrap lumber with protruding nails, and all other debris, shall be kept cleared from work areas, passageways, and stairs, in and around buildings or other structures.
Improper crane support	1926.1402(b)	The equipment must not be assembled or used unless ground conditions are firm, drained, and graded to a sufficient extent so that, in conjunction (if necessary) with the use of supporting materials, the equipment manufacturer's specifications for adequate support and degree of level of the equipment are met. The requirement for the ground to be drained does not apply to marshes/wetlands.
Lack of protective measures & insulation in the panelboards	1926.403(b)(1)	Electrical equipment shall be free from recognized hazards that are likely to cause death or serious physical harm to employees. This includes ensuring proper insulation, protection, and grounding of electrical wires. Additionally, 29 CFR 1926.962 requires grounding of transmission and distribution lines and equipment for the purpose of protecting employees.
Lack of Cable Management	1910.305(a)(2)(xi)	Cable assemblies and flexible cords and cables shall be supported in place at intervals that ensure that they will be protected from physical damage. Support shall be in the form of staples, cables ties, straps, or similar type fittings installed so as not to cause damage.
	1926.416(b)(2)	Working spaces, walkways, and similar locations shall be kept clear of cords so as not to create a hazard to employees.
Lack of Working Space Around Electrical Panels	1926.403(j)(3)	Sufficient space shall be provided and maintained about electric equipment to permit ready and safe operation and maintenance of such equipment. Where energized parts are exposed, the minimum clear workspace shall not be less than 6 feet 6 inches (1.98 m) high (measured vertically from the floor or platform), or less than 3 feet (914 mm) wide (measured parallel to the equipment). The depth shall be as required in Table K-2. The workspace shall be adequate to permit at least a 90-degree opening of doors or hinged panels.
Improper Origin for Temporary Wiring	1926.405(a)(2)(ii)(B)	Branch circuits shall originate in a power outlet or panelboard. Conductors shall be run as multiconductor cord or cable assemblies or open conductors or shall be run in raceways. All conductors shall be protected by overcurrent devices at their ampacity. Runs of open conductors shall be located where the conductors will not be subject to physical damage, and the conductors shall be fastened at intervals not exceeding 10 feet (3.05 m). No branch-circuit conductors shall be laid on the floor. Each branch circuit that supplies receptacles or fixed equipment shall contain a separate equipment grounding conductor if the branch circuit is run as open conductors.
Exposed Electrical Plugs	1910.303(g)(2)(ii)	In locations where electric equipment is likely to be exposed to physical damage, enclosures or guards shall be so arranged and of such strength as to prevent such damage.
Crane support close to edge of excavation	1926.651(f)	Warning system for mobile equipment. When mobile equipment is operated adjacent to an excavation, or when such equipment is required to approach the edge of an excavation, and the operator does not have a clear and direct view of the edge of the excavation, a warning system shall be utilized such as barricades, hand or mechanical signals, or stop logs. If possible, the grade should be away from the excavation.
Unprotected pit	1926.1424(a)(2)(ii)	Erect and maintain control lines, warning lines, railings or similar barriers to mark the boundaries of the hazard areas. Exception: When the employer can demonstrate that it is neither feasible to erect such barriers on the ground nor on the equipment, the hazard areas must be clearly marked by a combination of warning signs (such as "Danger--Swing/Crush Zone") and high visibility markings on the equipment that identify the hazard areas. In addition, the employer must train each employee to understand what these markings signify.

Identified Hazards	OSHA Standard Regulation	OSHA Standard Interpretation
Improper scaffold Platform	1926.451(b)(1) & 1926.451(b)(1)(i)	Each platform on all working levels of scaffolds shall be fully planked or decked between the front uprights and the guardrail supports as follows: Each platform unit (e.g., scaffold plank, fabricated plank, fabricated deck, or fabricated platform) shall be installed so that the space between adjacent units and the space between the platform and the uprights is no more than 1 inch (2.5 cm) wide, except where the employer can demonstrate that a wider space is necessary (for example, to fit around uprights when side brackets are used to extend the width of the platform).
Falling Object Protection due to Lack of Toeboard	1926.451(h)(1)	In addition to wearing hardhats each employee on a scaffold shall be provided with additional protection from falling hand tools, debris, and other small objects through the installation of toeboards, screens, or guardrail systems, or through the erection of debris nets, catch platforms, or canopy structures that contain or deflect the falling objects. When the falling objects are too large, heavy or massive to be contained or deflected by any of the above-listed measures, the employer shall place such potential falling objects away from the edge of the surface from which they could fall and shall secure those materials as necessary to prevent their falling.
Lack of Fall Protection, Missing Guardrails, Unsafe Behavior	1926.451(g)(1)	Each employee on a scaffold more than 10 feet (3.1 m) above a lower level shall be protected from falling to that lower level.
	1926.451(g)(4)(i)	Guardrail systems shall be installed along all open sides and ends of platforms. Guardrail systems shall be installed before the scaffold is released for use by employees other than erection/dismantling crews.
	1926.451(g)(1)(vii)	For all scaffolds not otherwise specified in paragraphs (g)(1)(i) through (g)(1)(vi) of this section, each employee shall be protected by the use of personal fall arrest systems or guardrail systems meeting the requirements of paragraph (g)(4) of this section.
Missing Mud Sills	1926.451(c)(2)	Supported scaffold poles, legs, posts, frames, and uprights shall bear on base plates and mud sills or other adequate firm foundation.
Improper storage of material	1926.250(a)(1)	All materials stored in tiers shall be stacked, racked, blocked, interlocked, or otherwise secured to prevent sliding, falling or collapse.
Missing Head Protection	1910.135(a)(1)	The employer shall ensure that each affected employee wears a protective helmet when working in areas where there is a potential for injury to the head from falling objects.
	1910.135(a)(2)	The employer shall ensure that a protective helmet designed to reduce electrical shock hazard is worn by each such affected employee when near exposed electrical conductors which could contact the head.
Lack of Protective Footwear	1910.136(a)	General requirements. The employer shall ensure that each affected employee uses protective footwear when working in areas where there is a danger of foot injuries due to falling or rolling objects, or objects piercing the sole, or when the use of protective footwear will protect the affected employee from an electrical hazard, such as a static-discharge or electric-shock hazard, that remains after the employer takes other necessary protective measures.
Lack of barricades for the swing area	1926.1424(a)(2)(ii)	Erect and maintain control lines, warning lines, railings or similar barriers to mark the boundaries of the hazard areas. Exception: When the employer can demonstrate that it is neither feasible to erect such barriers on the ground nor on the equipment, the hazard areas must be clearly marked by a combination of warning signs (such as "Danger--Swing/Crush Zone") and high visibility markings on the equipment that identify the hazard areas. In addition, the employer must train each employee to understand what these markings signify.

Identified Hazards	OSHA Standard Regulation	OSHA Standard Interpretation
Lack of Fire Prevention	1926.150	Fire extinguishers should be accessible and visible to all employees. Placing portable fire extinguishers near exits, high-risk areas and spaces with electrical equipment can improve response time during an emergency.
Fire hazard from Oil Spillage	1910.178(p)(3)	Spillage of oil or fuel shall be carefully washed away or completely evaporated and the fuel tank cap replaced before restarting engine. The primary risk is unintended ignition of fuel vapor, which can occur due to a single spark. Additionally, fuel spills cause soil contamination as they seep into the soil, leading to several environmental and safety issues.
Unattended Forklift	1910.178(m)(5)(i)	When a powered industrial truck (forklift) is left unattended, load engaging means shall be fully lowered, controls shall be neutralized, power shall be shut off, and brakes set. Wheels shall be blocked if the truck is parked on an incline.
Lack of Firm support for Electric Saw	1910.213(a)(6)	Circular saw fences shall be so constructed that they can be firmly secured to the table or table assembly without changing their alignment with the saw. For saws with tilting tables or tilting arbors the fence shall be so constructed that it will remain in a line parallel with the saw, regardless of the angle of the saw with the table.

Table A.2: Identified Hazards based on Good Safety Practices.

Identified Hazards	Hazard Interpretation
Plugged-in Electric Saw	Disconnect tools when not using them, before servicing and cleaning them, and when changing accessories such as blades, bits, and cutters.
Outlets are not fixed on Electrical Panel:	The openings in the electrical panel serve as access points for electrical conduits, cables, or wires. However, if these openings are not properly sealed, they expose live electrical components, posing an electric shock risk, and can accumulate dust and debris, potentially causing short circuits or corrosion.
Unsafe Condition for Rigger	Riggers should maintain a safe distance from the crane during operation. Being too close increases the risk of being struck by moving parts or loads. Also, clear communication between the rigger and crane operator is essential. Riggers should follow hand signals and stay visible to the operator.
Unsecured Site Entrance	An unsecured gate allows unauthorized personnel to enter the construction site. Workers or visitors who are not properly trained or equipped may accidentally fall from heights, trip, or encounter other hazards.
Unstable Metal fences	Fence collapse due to instability can cause injuries to workers or passersby, creating unsafe work environment.
Concrete Debris on the Ground	Concrete can percolate down through the soil and alter the soil chemistry, inhibit plant growth, and contaminate the groundwater. Its high pH can increase the toxicity of other substances in the surface waters and soil.
Improperly Parked Crane	Cranes should be parked away from passageways to prevent hindrance to personnel, equipment, and materials. Parking cranes in passageways increases collision risks and obstructs emergency egress during evacuations. Additionally, uneven ground or inadequate support can compromise crane stability, and poor visibility due to parked cranes which may lead to accidents.
Generator on Unstable Ground	Unstable surfaces may cause the generator to tip over, leading to injuries or damage. Place the generator on a non-combustible, non-conducting level surface slightly above ground level to prevent contact with rising water levels.
Fire Hazard at Generator Area	Improper refueling near the generator can lead to fires. Ensure safe refueling practices and store fuel away from ignition sources. A fire extinguisher should be readily available near the generator area.