Application of a Game Engine-Based Safety Training Tool in a Middle Eastern Country

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Abstract

The construction industry is known to have one of the most hazardous work environments leading to a high number of accidents and both serious and fatal injuries. One way to mitigate these accidents is by implementing proper safety training for construction workers. Traditionally, safety training is implemented using passive methods such as toolbox meetings, informative presentations, or videos. Recently, game engines have started gaining attention for safety training purposes. However, despite the extensive research on game engine-based safety training, still no research has developed a location-based tool to assess and train construction workers on safety measures. Moreover, this research focused on studying the adoption of such digital training methods for workers in the Middle East. The proposed tool was tested on 25 construction workers from the Middle East. Workers' feedback showed that 91% of participants preferred serious games over traditional training methods indicating the readiness of the construction industry to adopt such digital methods.

Keywords – Safety Training; Game Engines, Technology; Simulation; Construction Training.

1 Introduction

The construction industry is considered to be one of the most dangerous and fatal industries. In the UK, the construction industry accounts for the highest percentage of fatalities among all other industries [1]. According to the Occupational Safety and Health Administration (OSHA), the construction industry reported 971 fatalities in 2017, which accounted for 20.7% of fatalities among all other industries. Therefore, on a global scale, more effort has been channeled towards mitigating construction accidents [1]. Despite these efforts, the Middle East region is still falling short where by 48% of fatalities were solely reported from the construction industry in Saudi Arabia, and 33.2% in Kuwait [2].

A proactive way of mitigating construction accidents is through the proper training of workers. However, the commonly used safety training methods (e.g. toolbox meetings, presentations, handouts, brochures, and videos) are seen to be outdated and ineffective as workers do not have any engaging role and rather play a passive role throughout the training sessions by listening and absorbing the safety information. Moreover, these methods fall short when workers do not fully understand the language used to present the material [3]. As such, researchers have resorted to advanced technologies such as game engines to create interactive, realistic, and engaging training material for workers, which in some cases are referred to as serious games [4]. The use of game engines for construction safety training applications was found to have a positive impact on workers' motivation for training. It facilitated the learning experience, and had a more effective transfer of knowledge in comparison to the traditional training methods [5–8].

This research study takes the initial steps and aims to study the potential adoption of digital training methods in the Middle East. The study starts by giving a brief overview on the application of game engines in construction safety, and the personality factors which affect the safety behavior of workers on site. After that, the proposed tool's development is explained while highlighting the feedback obtained from construction workers who tested the tool.

2 Literature Review

2.1 Use of Game Engines in Safety Applications

Game engines have been gaining a lot of popularity especially in construction safety applications. Zhao et al. developed a training application to train heavy machinery operators on how to safely maneuver when near electric dangers such as electric poles and wires. Dickinson et al. developed a serious game to train workers on how to safely excavate trenches. Li et al. developed a multiple-choice question (MCQ)-based safety training tool where

workers had to answers questions based on virtual scenarios played within a game environment [9]. To enhance user experience and training realism, Yuan Ling et al. proposed the integration of BIM 4D with safety training. The researchers developed a tool which trained workers on excavation, structural, and exterior finishing phases [6]. While the aforementioned research studies focused solely on safety training applications, other studies used game engines to train workers on both skill and safety. Hafsia et al. trained workers on how to properly and safely erect steel formwork [10]. Using a similar method, Vahdatikhaki et al. developed an agent-based training simulator for pavement grading and compacting. The tool targeted training machine operators on how to compact asphalt pavements while both meeting safety and quality requirements [11]. More recent trends in safety training consist of the use of Augmented and Virtual Reality (AR/VR) technologies. In fact, researchers have found that the use of AR and VR for safety training offer workers a more immersive and realistic training environment [12,13].

All previous studies proved the effectiveness of using serious game engines over traditional training tools. As a matter of fact, the research conducted by Lin et al. showed that 100% of participants answered "Yes" to whether the game motivated them to refresh their knowledge on safety topics. Moreover, 80% of participants gave a score of 5 and 20% gave a score of 4 to assess how much the game increased their learning interests [5]. A similar assessment of another developed safety video game showed that 81% of participants answered "Yes" to whether the game facilitated their learning experience, and 86.5% answered "Yes" to whether the training method was more enjoyable than traditional training tools [6]. Another study showed that 80% of participants thought that the training program developed using the Unity game engine in particular was more useful than traditional training tools [9]. Furthermore, a framework, developed for safety integration within construction using serious game engines, scored 4 out of 5 on the ability to effectively transfer knowledge to users [7].

2.2 Factors Affecting Safety Behavior

In the attempt to mitigate safety hazards, several researchers have focused on developing mathematical models to link and predict safety climate, safety behaviors, and injuries based on different factors. Safety Climate has been defined as the perception or understanding of the organizational safety policies and procedures which the employees have towards their work environment [14,15]. Safety behavior has been defined as the worker's behavior in following safety and health requirements which, in turn, can mitigate accidents and injuries [16]. Additionally, Abbas et al. suggested that the years of experience of a worker may have a significant effect on his risk perception and thus on his safety performance[17]. Fang et al. studied the relation between different personal traits of workers and their safety climate. The research used factors such as marital status, number of family members to support, educational level, and safety knowledge. The findings of the research showed that individuals who are older, married, or have more family members are more likely to have a positive appreciation of the safety climate [18]. In a similar study, Zhou et al. used Bayesian networks to establish relationships between safety climate factors and personal traits with safety behavior. Personal traits included in the study were work experience, education, and drinking habits. The study showed that although higher work and education experience have a positive effect on safety behavior, other factors such as management commitment and workmate's influence had a higher effect. However, the optimal way to enhance safety behavior is by a joint strategy of enhancing all aforementioned traits [19]. Patel and Jha used 10 safety climate factors to predict the safe behavior of workers. The study showed that competence and individual perception of risk were found to be crucial for the prediction of safety behavior [20]. Another research studied the effect of economic features, self-esteem, and experience on safety behavior. The study showed that workers with a higher work experience showed more awareness vis-à-vis safety requirements and those with low self-esteem put themselves in many different unsafe situations. [21]. Beus et al. studied the effect of psychological traits on the safety of the workplace. Results revealed that individuals who are extraverts are more likely to engage in unsafe behaviors in an attempt to compete with others and achieve their goals and those who are conscientious are responsible and prefer to follow safety rules and avoid risks [22].

Despite the advancements in the literature, further development could be made in the application of game engines in construction safety. First, no research has investigated how a location-based training tool could be developed. Second, personality factors were not taken into consideration during the development phase of the training scenarios within the tools. Finally, no study has investigated the applicability of these training methods in the Middle East region. Thus, the overarching objective of this research is to develop a location-based safety assessment and training tool using game engines. As part of the this objective, this research will propose how some personality traits can be used in the assessment and training programs to increase safety moral and understanding among construction workers. Finally, the research will test the developed tool on construction workers in the Middle East region, and thus highlighting the possible adoption of such technologies in this region.

3 Methodology

This study uses Design Science Research (DSR) as the research methodology. DSR focuses on developing sound and practical tools to solve real world problems which are faced in the construction industry [23]. This research uses the game engine Unity to develop the proposed safety assessment and training tool. The tool has two main functions; (1) to assess and score each worker's safety knowledge and risk perception skills, (2) to safety train workers on the safety measures of their activity based on its upcoming execution location. After identifying the personality factors which have a direct effect on the worker's safety behavior, the assessment and training scenarios will be developed in Unity according to selected factors. Once the tool has been developed, it will be tested on construction workers and feedback regarding the effectiveness of the tool will be taken.

4 The Proposed Tool

4.1 Location-Based Navigation

The Activity Safety Trainer contains two programs, the Assessment Program and the Training Program. The UI was developed such that the user chooses the desired program at first as seen in Figure 1- a. Ideally, each worker will go through both programs. Figure 1 - b shows that if the user chooses the Assessment Program, the user then has to choose the required activity he wishes to perform the assessment on. On the other hand, Figure 2 - a and 2 - b show that if the user chooses the Training Program, the user will first choose the required activity and then the required execution location to train in. As this tool was developed to in a location-based perspective, the user will be trained based on the upcoming execution location of the activity. This is important as the training material does not only differ from one activity to the other, but also from one location to the other within the same location.

Figure 1 – (a) Home Screen

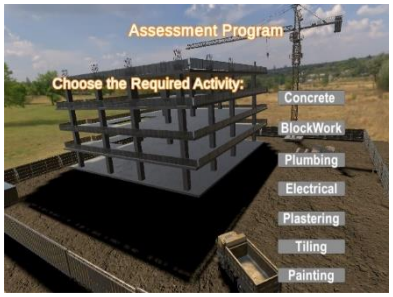

Figure 1 – (b) Assessment UI

Figure 2 – (a) Training Activity Selection

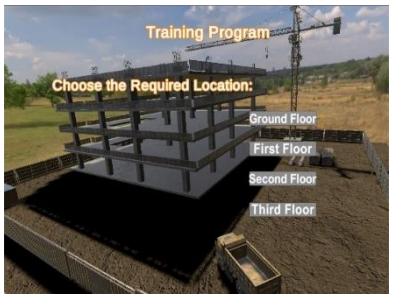

Figure 2 – (b) Training Location Selection

4.2 Integrating Personality Factors

Table 1 summarizes the personality factors that are sought to have a direct effect on the safety behavior of workers, as extracted from the literature. For simplicity, this study integrates only two of these factors in the development of assessment scenes, namely Safety Knowledge and Experience, and Risk Perception. The scenarios were developed such that 60% are focused on Safety Knowledge and Experience, while the remaining 40% is focused on Risk Perception. In the Assessment Program, the score is also divided the same way. Scenarios which focus on Safety Knowledge and Experience are those related to workers identifying missing Personal Protective Equipment (PPE) and other safety equipment. On the other hand, the scenarios which focus on Risk Perception develop dangerous incidents to check if the worker would notice or perceive them as

being hazardous. Figure 3 shows an example of how scenarios are developed for each case.

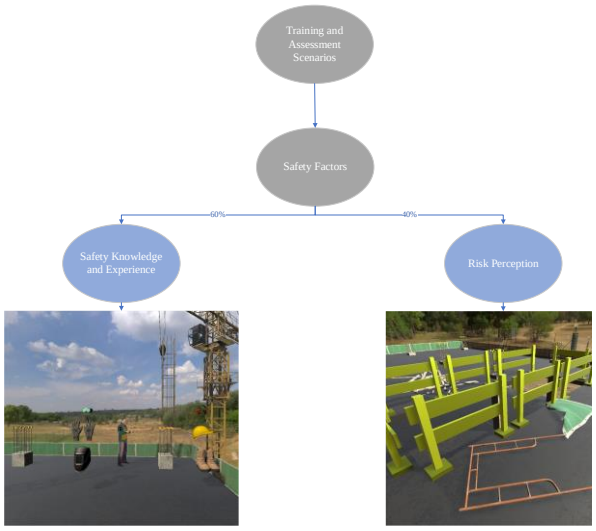

Figure 3 – Factors' Integration in Game Development

Table 1 – Effect of a Worker's Personality on Safety

Factor	Effect on Safety Behavior	References
Safety Knowledge & Experience	Positive	[18] [19] [20] [21] [24] [25]
Conscientiousness	Positive	[22]
Family Members to Support	Positive	[18]
Risk Perception	Positive	[20] [24]
Extraversion	Negative	[22]
Anxiety and Stress	Negative	[22]
Adventurous and Curious	Negative	[22]
Self Esteem	Negative	[21]

4.3 Gameplay Controls

The developed serious game covers different scenarios which enhance worker's safety knowledge and risk perception. Some scenarios were developed in different ways than others, and hence required a different type of gameplay controls. Game controls were developed in a way to be simple and easy to use by all workers regardless of their age and gaming skills. In the assessment program, certain scenarios are question-based scenarios where the user uses the mouse to press the button to indicate the right move or answer. Other assessment scenarios are played from a third person view where workers have to use the up and down arrow keys to move forward and backward respectively, and they have to use the right and left arrow keys to turn around or rotate. In these scenarios, workers are also required to use the mouse to point and click on safety hazards and missing measures. In the training program, the user has to only use the arrow keys to navigate through the site to learn about the safety hazards and measures.

4.4 Assessment Module

The assessment module aims to test the worker's safety traits and to allow planners to know whether this worker is qualified to safely work on the given activity. To achieve this objective, the worker went through a series of scenarios and obtained at the end a Safety Score (SS) ranging from 0 to 70 depending on the performance throughout the game. Figure 4 shows the virtual assessment environment within Unity.

Figure 4 – Assessment Program Environment

4.5 Training Module

The Training Program was developed in a way that would be understandable by all workers despite their age and educational level. Some workers might not know how to read or they read and speak a different language than the one adopted in the game. For this reason, the training game environment relies on visual aids to teach workers on correct and safe procedures as seen in Figure 5.

Figure 5 – Training Program Environment

5 Tool Testing and Results

Twenty-five construction workers from the Middle East tested the tool and gave their feedback by means of a survey. Their age ranged from 20 to 60 years old and their construction work experience ranged from 1 year to almost 40 years.

The workers were first asked to insert the Safety Score (SS) they got while testing the safety training program. 56% of the workers acquired an SS between 30 and 50 which is a medium SS range, while the other 44% acquired a score between 50 and 70 which is a high SS range. Despite having workers with very few years of experience, or old workers which might possess low computer proficiency skills , no worker got a score in the low score range between 0 and 30. These results might indicate the effectiveness of the use of serious games in safety training where workers were motivated to increase their training score. This can be supported by the fact that when asked if the game increased their motivation for learning, 96% acknowledged that digital games truly increased their interest in learning. Furthermore, all participants found that the game refreshed their safety knowledge where all workers strongly agreed that the game enhanced their perception of risks. Additionally, 96% of the participants found that the SS truly reflect their safety awareness, knowledge, and risk perception.

The participants were also asked whether they preferred being trained using traditional methods such as presentations, videos, and handouts, or using serious games. In this case, 92% of the participants opted for serious games while only 8% chose the traditional methods. Moreover, 92% of the workers were in favor of serious games being implemented in the Middle East. These results thereby indicate that the construction sector in the Middle East is ready to undergo a digital transition in its safety training methods.

6 Conclusion and Future Work

The overarching objective of this research was to test the deployment of digital training methods in the Middle East. This research study developed a tool for construction safety assessment and training using the Unity game engine. The tool was developed using a location-based approach so that workers are trained based on their assigned activity and its upcoming execution location. Moreover, various workers' personality traits sought to have a direct effect on their safety behavior were extracted from the literature and used in the development of the training game. The study also aimed at studying the potential adoption and implementation of digital games for safety training in the Middle East region. As such, the game was tested by 25 construction workers from the Middle East who answered a questionnaire related to the tool. Results revealed that workers were satisfied with the developed tool and approved of its effectiveness in mimicking the real construction environment and providing a realistic experience. In addition, the workers found it efficient in assessing and scoring their safety knowledge and risk perception skills and thereby showed excitement in having such a developed tool being implemented in the Middle East in lieu of traditional training methods. In a nutshell, the tool proved to increase workers' motivation for learning and interest in safety training in general.

This research is part of more detailed study regarding the use of serious games for safety training in construction. This study only focused on presenting the preliminary results regarding the development of the training modules and the feedback of the construction workers. The research was limited to a few number of participants due to the Covid-19 outbreak. Future work will focus on increasing the number of participants to gain more insight and feedback regarding the perception of workers toward these methods in the Middle East in particular. Moreover, more research needs to be done on how other personality factors or traits can be better integrated in the training and assessment programs.

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