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VIRTUAL REALITY APPLIED TO SAFETY TRAINING

Abstract: *According to the International Labour Organisation, approximately three million people die annually due to occupational accidents or diseases, with construction, mining, and manufacturing being the most affected sectors. One of the main contributing factors is the lack of adequate safety training programs, combined with poor safety knowledge. Literature suggests that immersive technologies, such as virtual and augmented reality (VR/AR), effectively enhance occupational safety training by allowing workers to experience hazardous scenarios in a controlled environment. This enables skills development without exposure to real-world risks. DigiRescueMe and STRIM European projects were designed with this principle in mind. DigiRescueMe focuses on miners' rescue training for professionals, while STRIM develops mining curricula with a special emphasis on occupational safety and health for students and mining professionals. The first phase of both projects involved identifying the most pertinent training content through focus group discussion and needs analysis. Then, realistic virtual scenarios were developed using Unity 3D, incorporating 3D-scanned objects via Peel3D technology to enhance realism. Currently, these scenarios are being tested by students and professionals, with feedback collected for further improvement.*

Keywords: immersive tools, safety engineering, occupational health and safety

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INTRODUCTION

Every year, around 3 million people die from occupational accidents or diseases, and 395 million workers sustain work-related injuries.[1] Data shows that about 63% of the fatal accidents are centred in just four sectors: agriculture, construction, forestry and fishing, and manufacturing. Taking a closer look at the European context, the scenario does not differ that much, with the construction sector at the top of the list with 22.9% of fatal accidents, and again the same sectors listed before, with transportation joining the list with around 15.6%.[2] Stress and mental health factors, fatigue, improper material handling, or use of inadequate personal protective equipment are some of the listed accident root causes, but, interestingly, a lack of safety programs is also mentioned in the literature (Barkhordari et al., 2019; Ivascu & Cioca, 2019; Mohandes et al., 2022). Particularly focusing on this latter issue, immersive tools have been paving their way through training agendas, especially occupational safety training. But what exactly are they? "Immersive tools" are computer-generated simulations with spatial and visual dimensions. Along the virtual continuum, virtual and augmented reality and their overlaps (Handa et al., 2012) allow programming of realistic (hazardous) scenarios that can be tested/used without actually putting the trainees in real-life threatening scenarios (Babalola et al., 2023). Despite their tremendous potential, it is important to note that these technologies are not here to replace traditional training methods but instead to complement them (Rey-Becerra et al., 2023).

LITERATURE REVIEW

A systematic literature research on immersive technologies as occupational safety training tools showed that, without surprise, construction is the sector investing more in safety training (Afzal & Shafiq, 2021; Al-Khiami & Jaeger, 2023; Alzarrad et al., 2024; Bao et al., 2024; Feng et al., 2024; Getuli et al., 2021; Rey-Becerra et al., 2023; Rokooei et al., 2023; Shringi et al., 2022; Xu & Zheng, 2021; Yu et al., 2022), followed by mining (Gürer et al., 2023; Pedram et al., 2020; Zujovic et al., 2021), manufacturing

[1]https://www.ilo.org/resource/news/nearly-3-million-people-die-work-related-accidents-and-diseases
[2]https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Accidents_at_work_statistics

(Dhalmahapatra et al., 2021), transportation (Haj-Bolouri et al., 2024), and healthcare (Fujiwara et al., 2024). The analysed training domains can be easily divided into hazard identification and procedures training to improve safety awareness and decrease accident occurrence. To acquire a better perception of whether immersive tools are a better fit for safety training, control groups were used, whereby data showed that motivation and engagement, as well as overall training results, improved when compared to traditional classroom teaching methods (Al-Khiami & Jaeger, 2023; Alzarrad et al., 2024; Evangelista et al., 2025; Lu et al., 2022; Rey-Becerra et al., 2023; Rokooei et al., 2023). Nonetheless, it has to be mentioned that few studies provide long-term assessment to disclose the actual effectiveness of such training programs in long-term knowledge retention. The ones which did, however, obtained positive scores (Feng et al., 2024; Pedram et al., 2020; Stefan et al., 2024). Despite the said advantages of immersive tools, challenges remain. The cost of implementation and the resistance to adopting new technologies are notable barriers that cannot be ignored. Nevertheless, immersive tools present a transformative potential for occupational safety training, bridging theoretical knowledge with practical application.

DIGIRESCUE ME & STRIM PROJECTS

The *Standardization and Digitalization of Rescue Education in Mining* (STRIM) project, coordinated by the Faculty of Engineering of the University of Porto (FEUP), aims to develop an innovative digital curriculum for safety training in the mining industry, using virtual reality (VR) and augmented reality (AR). Funded by the Erasmus+ program No. 101083272, it involves institutions from Portugal, Angola, Mozambique, and Turkey. Activities include needs analysis, development of digital content, and validation of immersive tools for occupational safety training. The DigiRescueMe project, funded by the Erasmus+ program No. 2021-1-TR01-KA220-VET-000028090, aims to standardise and digitise mine rescue training. Coordinated by Dumlupinar University (Turkey), it involves FEUP and other European institutions. It focuses on creating modern curricula integrating technologies such as VR simulations and 3D techniques, promoting innovative educational practices in the mining sector. Both projects, STRIM and DigiRescueMe, stand out for their integration of immersive technologies, such as virtual and augmented reality, in the training of mining professionals. While STRIM focuses on occupational safety training, DigiRescueMe concentrates on mine rescue training. Immersive tools provide safe, realistic, and interactive learning environments, allowing trainees to acquire practical skills without exposure to real risks, reflecting a growing trend in professional education and industrial safety. This article aims to show how virtual reality, as an immersive tool, is being used to enhance safety training in these projects.

METHODOLOGY

The first phase of any training program is identifying the key content and materials. Therefore, a needs analysis was carried out for each project with this intent. Occupational health and safety technicians and mining professionals, as well as university educators and students, were interviewed and added to focus group discussions. It is important to bear in mind at this point that both projects encompass several institutions and, in their turn, are located in different geographical contexts and, therefore, cultures, which were also taken into consideration to draft the respective programs. Once the programs were drafted, the next step was to identify and draft computer-based scenarios that would allow building the immersive part of the training. Each scenario was thoroughly designed to consider every “real-life” bit that one would encounter in the real world using the Unity engine and C# in Visual Studio. Animations and sound effects were incorporated to stimulate the maximum number of senses and make the scenario as authentic as possible, creating a greater sense of immersion. Animations were created in *Unity*, using free *prefab* libraries-sourced objects. To enhance detail, additional objects were scanned using the *Peel3D* (Figure 1) scanner and incorporated into the scenarios.

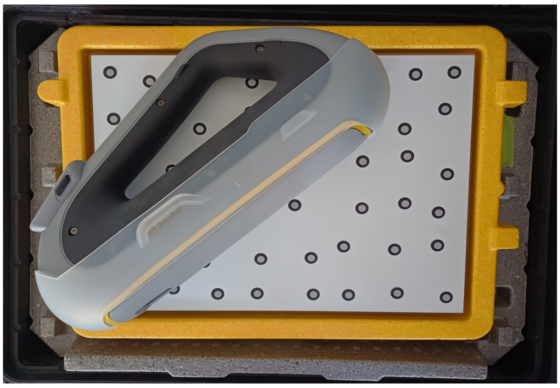

Figure 1. *Peel3D equipment*

The scenarios were built in a problem-based learning (PBL) approach, leading to the development of several *serious games*. By moving through each step of the way, the trainee has the chance to test their knowledge but also to learn the most appropriate action considering each learning outcome. To test the developed scenarios, the HTC VIVE equipment was used. It consists of one head-mounted display (HMD), two controls, and two sensors that require a minimum-distancing step up in order to function properly and, for the same reason, a maximum of 5.5 metres. The sensors have to be mounted at head height so they can pick up the signal emitted by the HMD. This means that the trainee also has to move exclusively within the radius of the equipment. Otherwise, the signal is lost, and the scenario blacks out. At the same time the scenarios were being built, a literature search was conducted to identify the most adequate questionnaires to test the developed materials. From the identified materials, two validated questionnaires stood out for their pertinence and adequacy to the testing phase: the System Usability

Scale (Brooke, 1996) and the Game Experience Questionnaire (GEQ) (Law et al., 2018). The SUS questionnaire is a 10-item questionnaire with answers on a 5-point Likert scale, used to evaluate the perceived usability of systems. It measures efficiency, effectiveness, and user satisfaction. It generates a score from 0 to 100 and is widely used for its simplicity, reliability, and general applicability. The GEQ is a multidimensional instrument for assessing the subjective experience of gamers. It also uses Likert scales to measure emotional, cognitive, and sensory factors. The GEQ questionnaire focuses on two moments: the "in-game", where the participant evaluates their performance and feelings during the *serious game*, and the "post-game", where the participants evaluate how they felt after the game. All the scenarios are currently undergoing testing by both students and professionals in the fields of mining engineering and occupational safety and health.

RESULTS AND DISCUSSION

The scenarios were made under the considerations detailed in the Methodology section. Three of those will be presented here, with the details discussed. The first one is a quarry scenario where the cardiopulmonary resuscitation (CPR) principles were tested (Figure 2). For this scenario specifically, the Automated External Defibrillator was digitised using the *Peel3D* and introduced in the *serious game*, as seen in Figure 2.

Figure 2. *Quarry scenario with CPR training*

As the scenarios were developed, subjects' feedback was gathered regarding their realness and proximity to reality, whereby small elements were added in the background to add a sense of reality to the quarry. This same exercise was later applied to every other scenario.

The second scenario propels users to take action upon the identification of an underground mining fire (Figure 3). The serious game development uses multiple-choice questions to guide the trainee throughout the scenario. In case the wrong answer is chosen, the box highlights in red colour, as seen in Figure 3. In case the user chooses the correct answer, the game moves on. Though real sounds were added to the scene, it is noted that, to increase the stress level as if in a real-life event, other aids could be used to improve the immersion experience, such as heating sensors, smoke machines, or camera effects (for example, changing colours or shaking/vibrating). However, that type of equipment would increase the overall step-up cost and would require a particular configuration room, contrary to the almost portable option of the HTC VIVE equipment, which has only the requirement for space for the free trainee movement.

Figure 3. *Underground mine fire scenario*

Finally, in scenario three, a worker is found unconscious, and the trainee is asked what the rescue operation actions would be (Figure 4). Considering the content complexity, even if the trainee provides the correct answer, the system "gives back" additional information to increase awareness of the subject, in this case – the need for an immediate response to improve the victim's chances.

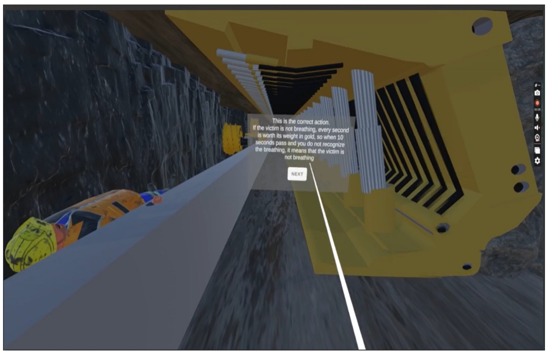

Figure 4. *Underground mine occupational accident scenario*

In this scenario, it is also quite complicated to increase the immersion level, taking the serious game to the next level instead of its being regarded as "just" a game.

Every scenario was created to incorporate real-life detailed dimensioning, exploitation, and technical principles. Nonetheless, it is important to mention that a severe limitation was encountered in the scenario development, as the relation between computer processing and the number of objects inside the scenario must be balanced for the computer to perform well. The users reported that the characters' movements "replicated well" real-life situations, enabling the player to act as they would in an authentic context. According to the feedback received so far, this tool is believed to help increase mining industry safety by providing training situations that empower workers to act.

CONCLUSION

Immersive tools such as virtual reality show great potential in occupational safety training, being explored in that direction by the STRIM and DigiRescueMe projects. The feedback gathered so far has led to the belief that using these tools, education on rescue operations (and overall safety) can be improved. With further investigation and proper development, hopefully, they will contribute to enhancing safety programs, raising awareness of mining-related hazards and accident reduction through training improvements.

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