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The Use of Virtual Reality Technology in Employee Safety and Health Training. A Case Study of an Enterprise from the Smelting Industry

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Abstract

Improving results in the safety and health management of employees performing particularly hazardous work (e.g. in the smelting industry) depends mainly on effectively conducted occupational safety and health training. To prevent accidents at work and occupational diseases, existing solutions in this area should be complemented or replaced with innovative ones. Virtual Reality (VR) technology offers excellent opportunities in this area. This article is both theoretical and empirical in nature. It aims to present (1) the potential of VR in occupational safety and health (OSH) training from the theoretical perspective and (2) practical solutions for using VR in OSH training in the particular case of a smelting industry enterprise. For the purposes of the article, an analysis of the literature on the subject and a descriptive case study were used. The literature on the subject provides evidence that VR can be successfully used in occupational safety and health training. The analysed company is in the phase of testing VR technology in on-the-job training for particularly hazardous work. Initial reports from the project are promising. The authors recommend actions to eliminate/limit the identified implementation weaknesses. They also hope that the article will encourage safety and health managers to be interested in the issues discussed and facilitate the design and implementation of more effective occupational safety and health training.

Keywords: virtual reality, safety and health training, on-the-job training, hazardous work, smelting, case study

JEL Classification Codes: J28, J24, O33, L72, M53

Introduction

The European Commission's Strategic Framework on Health and Safety at Work 2021–2027 establishes key priorities and actions aimed at enhancing health, safety, well-being, and productivity of workers while addressing rapid changes in the economy, demography, and work patterns (European Commission, 2021). The new strategy is centred around three overarching objectives: anticipating and managing change in the context of green, digital, and demographic transitions, enhancing prevention of work-related accidents and diseases; and working towards a Vision Zero approach to eliminate work-related deaths, coupled with increasing preparedness to respond to current and future health crises (Ramos, Cotrim, Arezes, Baptista, Rodrigues, Leitão, 2022).

In light of the above, companies that aim not only to protect but also to promote physical and mental health of their employees should adopt a comprehensive approach to occupational safety and health (OSH). This means that, in addition to systemic actions (such as implementing, maintaining, and continuously improving an OSH management system), efforts focusing on technical safety (securing machinery, equipment, and workstations) as well as behavioural safety (Behavioural-Based Safety) are necessary (Koźlik, 2008). These actions should primarily have a precautionary and proactive nature to prevent risks, injuries, and health problems related to work (Pandey, Kiran, Parhi, Singh, Jha, 2023). New and emerging OSH risk factors, such as COVID-19, have clearly demonstrated that contemporary safety and health management systems must also be resilient and responsive. This allows for the swift adoption of appropriate measures to address unforeseen contexts and mitigate both conventional and novel occupational hazards (Ramos et al., 2022).

The success of the OSH management system depends on many factors. One of them is effective OSH training. It is an essential part of a hierarchy of prevention measures and can be described as a range of efforts undertaken to engage trainees to affect their motivation, behaviour, and attitudes to improve workers' safety and health. OSH training equips employees with the necessary understanding and awareness to identify potential workplace hazards. It fosters a mindset that empowers individuals to consciously assess situations for potential risks and dangers. Moreover, it imparts procedural knowledge, enabling employees to respond appropriately and prevent working under hazardous conditions (EU-OSHA, 2020; O'Connor, Flynn, Weinstock, Zanoni, 2014). According to the Labour Code, employees must not be allowed to perform work for which they do not possess the required qualifications or necessary skills, as well as adequate knowledge of regulations and principles of occupational safety and health. Employers are legally obligated to provide initial safety and health training before allowing employees to work and conduct periodic training during employment. The international standard ISO 45001:2018 "OSH management systems – requirements with guidance for use" emphasise that organisations should identify necessary competencies, take actions to acquire and maintain them, and evaluate their effectiveness. These competencies include the knowledge and skills needed to identify hazards, address occupational health and safety risks related to their work and workplace, prevent accidents at work and occupational disease.

Training, as a pivotal component within the OSH management system, should undergo continual enhancement with regard to its utility, appropriateness, and effectiveness, akin to the other elements comprising the system. To become more effective, objectives, content, and safety and health training methods should be constantly reviewed. Managers are urged to actively seek innovative solutions that facilitate the adaptation of OSH training to evolving workplace dynamics and the emergent requirements of organisations and their workforce. The rapid evolution of technology presents substantial opportunities to optimise the processes and outcomes of OSH training initiatives (EU-OSHA, 2020; EU-OSHA, 2023).

The above pertains, among other things, to safety training methods, which should be cost-effective, performance guaranteed, and engaging for the participants. Many researchers emphasise that traditional OSH training methods, including lectures, seminars, online exercises, non-interactive videos, paper-based safety guidelines, and on-site trainings, find it increasingly challenging to meet these requirements. They point to the following limitations of traditional methods: limited engagement levels, difficulty transferring the training to the real world, time inflexibility, and training inconsistencies due to instructor dependency (Burke, Sarpy, Smith-Crowe, Chan-Serafin, Salvador, Islam, 2006; Gao, Gonzalez, Yiu, 2019; Schwarze, Kampling, Heger, Niehaves, 2019). Other researchers highlight that many training programmes are often conducted conventionally and are not tailored to the diverse and specific needs of the participants. Moreover, methodologies with low physical and psychological resemblance to the hazardous environment are commonly used, resulting in inadequate sensory information to create a genuine perception of being in that specific place (Cordeiro, Santos, Winkler, 2023).

Considering the above, this article aims to present the potential of VR in OSH training from a theoretical perspective. Following this, it presents practical solutions for using VR in OSH training in the particular case of a smelting industry enterprise. For the purposes of the article, an analysis of the literature on the subject and a descriptive case study were used.

Applications of VR technologies for OSH training – benefits and limitations

Virtual reality (VR) is a promising technology that has become increasingly popular in recent years. Many researchers define it by referring to its three properties: (tele-) presence, interactivity, and immersion (Walsh, Pawlowski, 2002). Wohlgenannt, Simons, and Stieglitz (2020) assert that VR leverages immersive technologies to simulate interactive virtual environments or virtual worlds. Users become subjectively involved and feel physically present in these environments. Babalola et al. (2023) emphasise that VR can be defined as a computer-generated three-dimensional (3D) simulation of real-world scenarios. By utilising electronic devices like head-mounted displays (HMDs), users can immerse themselves in and interact with these simulated environments.

Intensive development and recent advancements in VR technology (reduction in price, improvements in the usability and ergonomics of VR hardware, quality of its output) have resulted in various fields and sectors of its application (Stefan, Mortimer, Horan, 2023). Apart from gaming and entertainment, VR is used in education. Other fields include retail, transportation, energy, consulting, insurance, healthcare, and sports. Industries such as defence, real estate, architecture, and tourism, have also used VR. Additionally, it is used in military training, law enforcement, construction and manufacturing, journalism and media dissemination, scientific visualisation, and engineering. VR also supports HR activities like personnel recruitment, assessment, onboarding, and development. It is worth emphasising that this list is not exhaustive, and the number of VR applications is growing (Wohlgenannt, Simons, Stieglitz, 2020; Hamad, Jia, 2022; De Back, Tinga, Louwerse, 2023).

The literature review on the subject of VR applications highlights that it has been successfully applied in training, including OSH training (Buttussi, Chittaro, 2021; Stefan, Mortimer, Horan, 2023). Norris, Spicer, and Byrd (2019) believe that thanks to the flexibility offered by VR, OSH training programmes can be customised to address the specific needs of virtually any industry and replicate numerous environments and scenarios. Research reports on this subject primarily come from industrial sectors such as transportation, construction, manufacturing, mining, healthcare, oil and gas and chemical industries. The OSH hazards addressed by VR training include but are not limited to fire, fall, impacted by electrical and chemical components, working at heights hazards (Gao, Gonzalez, Yiu, 2019; Babalola, Manu, Cheung, Yunusa-Kaltungo, Bartolo, 2023). It is worth emphasising that numerous applications of VR for OSH training take place in industries where the severity of hazardous events/exposures is high. According to Burke et al. (2011), employees in high-risk industries should undergo engaging training that simulates real-life situations to enhance safety knowledge and improve safety performance.

VR technology offers a significant opportunity to enhance the effectiveness of OSH training. This is primarily attributed to its numerous advantages and profits, which can benefit all stakeholders. As highlighted in the literature, the advantages of VR seem to address the limitations of traditional training methods mentioned earlier, thereby transforming conventional teaching approaches into ground-breaking training experiences (Babalola et al., 2023). VR has the capability to transpose trainees into scenarios with a high level of realism by recreating complex representations of work environments, especially those difficult, expensive, or dangerous to replicate in the real world due to financial constraints or safety concerns (Norris, Spicer, Byrd, 2019; Stefan, Mortimer, Horan, 2023). One significant advantage is the ability to train for dangerous or expensive scenarios in a controlled virtual environment where participants can make mistakes and experience safety failure (e.g. injuries, fatalities, near-hit incidents) without serious consequences. This not only reduces the risks associated with simulating potentially hazardous situations but also allows for the depiction of non-existent scenarios through VR (Xu, Zheng, 2020; Dhalmahapatra, Maiti, Krishna, 2021). The immersive nature of VR enhances understanding of safety protocols and real-life job experiences. It offers an opportunity to practice identifying and assessing hazards and risks, bridging the gap between classroom-conducted safety training and real-world, on-the-job hazards (Norris, Spicer, Byrd, 2019; Joshi, Hamilton, Warren, Faucett, Tian, Wang, Ma, 2021). Thanks to attractive and immersive experiences, VR-based OSH training can increase trainees' commitment and motivation to learn and improve skills (Abich, Parker, Murphy, Eudy, 2021; Shiradkar, Rabelo, Alasim, Nagadi, 2021). It also allows ongoing monitoring of participants' progress, which facilitates assessing their skills, identifying areas requiring additional training, and providing immediate feedback (Dhalmahapatra, Maiti, Krishna, 2021; Norris, Spicer, Byrd, 2019).

In addition to the numerous advantages of using VR technology in OSH training, one should be aware of its limitations. A review of the literature allows to identify the notable ones. However, it is worth noting that this issue is still poorly recognised (Schwarze Kampling, Heger, Niehaves, 2019). In the early stages of VR development, a significant limitation was its high cost and the substantial time and effort required to create usable training scenarios. As advancements in this field continue and the number of companies specialising in creating tailor-made scenarios in VR increases, accessibility to this technology grows (Norris, Spicer, Byrd, 2019). However, many researchers emphasise that for many organisations, the development of VR simulations is still time-consuming, expensive, and requires a lot of computing power, and there is a lack of available expertise for the development of VR interactive contents (Babalola et al., 2023). An identified limitation is that training platforms using immersive technology are restricted by the currently available hardware and software. The level of realism and immersion is contingent on the progress of these technologies and the company's investment in them, among other factors (Cordeiro, Santos, Winkler, 2023). Babalola et al. (2023) point out that current HMDs were designed for entertainment and media consumption rather than prolonged usage in training settings. Therefore, their use for long-duration training may be problematic. Furthermore, VR could be perceived as unsuitable for training purposes, given the diverse learning styles among trainees, variances in gaming proficiency, and considerations related to disabilities. According to the researchers, an additional challenge is the lack of effective communication methods between trainers and trainees engaged in a virtual environment. Effective communication is crucial, as trainers must comprehensively grasp the difficulties encountered by trainees while utilising immersive technologies and offer timely solutions using appropriate hardware and software tools. The most common drawback is cyber-sickness both during and after the VR experience (Schwarze Kampling, Heger, Niehaves, 2019). Individuals experiencing cyber-sickness may exhibit symptoms such as pallor, sweating, nausea, eyestrain, vomiting, disorientation, or dizziness due to excessive stimulation by cyber technologies or equipment. It causes discomfort which can disrupt the user's immersion and, consequently, hinder an individual from concentrating on the learning context or executing a specific task (La Viola, 2000; Shi, Ning, Chen, Dhelim, 2024).

With an increasing number of practical areas in which VR is applied, including OSH training, numerous researchers draw attention to the effectiveness of VR-based training. Many of them emphasise that this issue is still too poorly explored and requires further, in-depth research (Cordeiro, Santos, Winkler, 2023; Strojny, Dużmańska-Misiarczyk, 2023). According to Bell et al. (2017), the challenge is understanding whether technology-based training effectively achieves the desired training outcomes and the factors influencing its effectiveness. Srinivasan et al. (2022) emphasise a need to develop systematic approaches to measure the effectiveness in achieving the desired training outcomes. Strojny and Dużmańska-Misiarczyk (2023) emphasise that research on the effectiveness of VR-based training is very diverse, and studies in this area sometimes lack common theoretical and methodological foundations. Benitti (2012) highlights that both industry and academia should understand the effectiveness of new technologies and resist getting caught up in what may be nothing more than a passing fad.

Method

The method used in this study was a descriptive case study which aimed at describing in detail the VR safety and health training (on-the-job training) in hazardous work environment for blue-collar workers. It allowed the researchers to gain concrete and contextual in-depth knowledge about the advantages and disadvantages of applying VR in a particular organisation. It was also chosen purposefully to show similar results to what was described in the literature (literal replication) as it is advocated in the literature (Perry, 1998).

Table 1. Case-study methodology framework

Purpose of the case study research	Reason to use case study research	Type of case study research	Methods of gathering data	Data analysis of case study research
Practice-oriented	Description	Descriptive	Observation, document review, participant observation and physical artifacts.	Data display, explanation building, direct interpretation, content analysis, within-case analysis.

Source: (Ebneyamini, Sadeghi Moghadam, 2018).

According to Yin (2018) case study research with the description of one case is justifiable when the case under investigation is the quintessential example of a particular phenomenon. The case described in this paper meets the aforementioned criterion. Additionally, the use of the case study method is even recommended in today's volatile environment with the growing frequency and magnitude of changes in technology and managerial methods (Ebneyamini, Sadeghi Moghadam, 2018). Table 1 shows the framework of the case-study methodology.

Research questions

Case studies methodology recommends "how" and "why" research questions which are the most appropriate for it (Ebneyamini, Sadeghi Moghadam, 2018; Yin, 2018). In this context, we stated 5 research questions to get an in-depth view of how and why the VR based on-the-job training was implemented for smelters:

1. What are the goals of the implementation and use of VR in the case study on-the-job training for smelters? How are they related to a comprehensive approach to OSH? Do they affect behavioural patterns? Better learning outcomes?
2. Is the efficiency and effectiveness of the VR method examined in the context of: health and safety (lower accident rate, greater awareness of dangerous behaviours), development (faster growth of competences), performance (better quality of work, fewer deficiencies, failed products), well-being (greater satisfaction, less stress, commitment). By what methods/indicators?
3. How does the training influence workers? How do they assess its usability? Do employees participate in the creation of scenarios? Do they perceive them as real possible events?
4. What are the weaknesses of VR training (e.g. lack of realism, motion sickness, poor flexibility to the changing circumstances), and how does the company deal with them and/or prevent them?
5. What solutions are implemented to improve the method in the context of goals, efficiency, effectiveness, and better fit to the employees' well-being and engagement?

To meet the standards of high reliability of case study design a "case study protocol" (Priya, 2021) was applied, including the following elements:

1. An overview of the on-the-job training and its objectives.
2. A detailed description of the sources and procedure of data collection.
3. Guidelines for analysing data and reporting findings.
4. The discussion of stated research questions.

Description of a case study (on-the-job training) and its objectives

The first element of a case study protocol addresses the description of on-the-job training and its objectives. It also refers to answering the first research question.

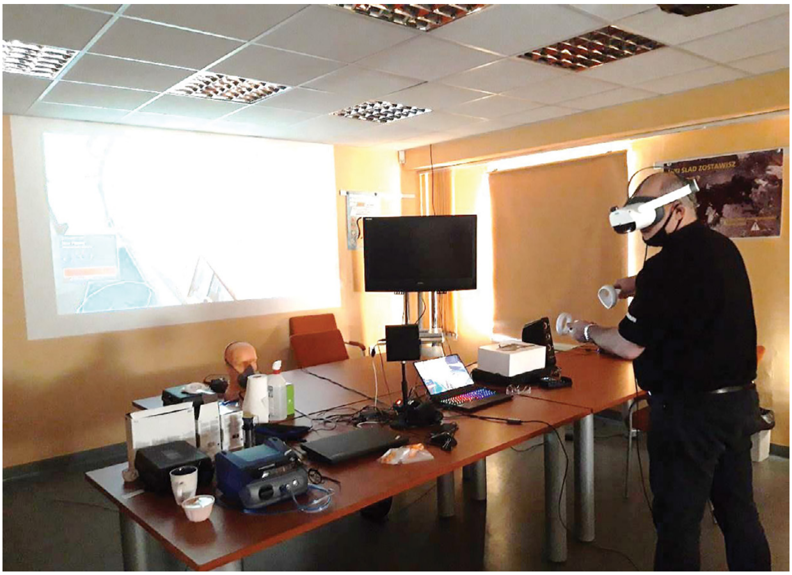
This case study concerns a smelting industry enterprise (SIE) that has integrated VR technology into its existing OSH training solutions in the field of on-the-job training of employees performing particularly dangerous work. SIE employs about 2500 people. Most of them are production workers, operating in a demanding and hazardous work environment. The most important risk factors are harmful physical and chemical agents such as noise, lead, liquid metal, hot microclimate, poisonous fumes, explosion or fire, and working at heights.

As part of the implemented, maintained and constantly improved occupational health and safety management system (ISO 45001:2018), the company undertakes a number of different activities. Such an approach is primarily intended to ensure the most comprehensive protection of safety and health of employees and the achievement of OSH objectives (e.g. reducing the number of accidents, occupational diseases). At the same time, in addition to systemic safety activities (e.g. occupational risk assessment, audits, management reviews), the company carries out tasks aimed at improving technical safety (e.g. modern machinery, equipment security) and behavioural safety (e.g. behavioural audits, health and safety culture research). It is worth noting that many of these activities are proactive and voluntary, i.e. they go far beyond the sphere of practices defined by law (e.g. identification and analysis of near misses). It is also very important to work on the awareness of employees and to develop good working habits when working in exposure to harmful factors. Despite their diversity, these activities are mutually consistent and in line with established OSH management policies and objectives. The company is also successful in ensuring broad employee participation in their implementation (e.g. a system of employee initiatives has been launched, under which employees submit proposals to improve safety). It is worth emphasising that, despite the wide range of activities undertaken to improve workplace conditions, some company staff still work in environments with high exposure to health-hazardous factors, both chemical and physical.

A very important element of the OSH management system in SIE is employee training in OSH. The main objective of the activities undertaken by the company in this area is to build the competences of employees necessary to achieve the current and future objectives of the OSH system (e.g. reduce the number of work-related accidents and occupational diseases). In accordance with the law, employees of SIE are subject to initial and periodic training. The first ones are carried out before the employee is allowed to work. Their aim is to provide them with the knowledge and skills necessary to perform their work taking into account safety regulations and rules and to familiarise them with the hazards occurring at specific workplaces. This training includes general instruction and on-the-job manual. Periodic training is repeated during the employment. It aims to remind and consolidate OSH knowledge and familiarise participants with new technical and organisational solutions.

In the SIE, many employees perform particularly dangerous work. Systematic behavioural audits have shown that a significant percentage of irregularities and dangerous behaviours have been found among workers operating blast furnaces, where employees are exposed to many hazards, including liquid metal and chemical agents. Failure to use personal protective equipment such as safety goggles or half/full-face masks in such working conditions and any deviation from the safe work procedure can cause workplace accidents, occupational diseases, or equipment failures. Therefore, with the idea of continuous improvement, the company decided to increase the effectiveness of its existing on-the-job training for particularly dangerous work by using VR technology.

Picture 1. VR training station



Source: SIE' internal materials.

The VR project started at the beginning of 2023 and is still in the testing phase for volunteers (new and experienced workers) who want to test or improve their skills. An external IT company, experienced in creating VR applications, was selected to prepare the VR training. The development process of the training began with an analysis of workstation documentation as well as real-life observation, which allowed the IT developers to familiarise themselves with the specifics of the process to be transferred into the virtual environment. Then, the programming work began, during which great emphasis was placed on strict mutual cooperation. As a result, a simulation twin to the real processes of burning and plugging the copper drain hole and working at height was created. The whole process of creating the VR training took 6 months. VR goggles Pico Neo 3 Pro and a computer with a dedicated graphics card are used during the training simulation (Picture 1).

There are two scenarios addressed to smelters and workers at height. The first scenario is for learning how to burn and plug drain holes (Picture 2).

Picture 2. Burning a drain hole in virtual reality

Source: SIE' internal materials.

It is an activity that is performed around 20,000 times a year by about 400 employees working in direct contact with liquid metals and harmful agents. The activity requires the employee to be particularly careful, mentally and physically fit and familiar with procedures. Erroneous operations may result in serious consequences in the form of accidents at work, equipment failures and, consequently, technological downtime. On the basis of the work standardisation cards, an application was developed that allows employees to learn safe habits of dealing with dangerous activities in virtual reality before they are allowed to work at a real workplace. The participant of the VR training, using the tools available in the application, burns and plugs the copper drain hole. With the help of special goggles and pads, employees train the correct sequence of movements and procedures for the operation of blast furnaces. Dedicated software reflects the interior of the steelworks, taking into account all elements of its infrastructure. Holding the controllers in hands, the trainee can (literally) go through the entire technical process and perform all the actions. In virtual reality, the employee is informed step by step about hazards and possible emergencies. Messages about what to do in the event of a risk appear in the application. The VR simulation for burning and plugging the copper drain hole was divided into the following stages: (a) preparing the employee's clothing and identifying the elements of the scene, (b) preparing before burning, (c) burning the drain hole, checking and plugging the trigger. It takes 1.5 hours for the participant to undergo all the training in this scenario.

In the first stage, the user must take care of their own safety. To do this, one becomes familiar with the necessary personal protective equipment. Next, the trainee gets acquainted with the elements of the scene, i.e. the objects necessary to burn and plug the trigger. This is a very important stage that makes the user aware of the danger of the upcoming challenge. The second stage focuses on preparing the necessary tools and checking the systems present in the steelworks. The user must prepare the drain plugs and the oxygen hose, check the operation of the control panels and the ventilation system, light a fire in a coke oven, check the patency of the gutters. In this stage, the user is familiarised with all the steps that need to be performed before proceeding to burn the drain hole. During the procedure, they are informed about potential dangers resulting from failure to comply with their duties or negligence. This part of the simulation is crucial for a safe and fluent move to the next steps of the training. The last stage of the training proceeds with the most dangerous activities. The task is to burn the drain hole and secure and plug the trigger. Thanks to VR technology, possible mistakes during burning are not dangerous for the trigger. Next, the user controls the trigger which means taking care of the correct flow of liquid copper. The last task is to plug the drain hole with a plug, several meters long.

In order to create a realistic simulation, it was necessary to reproduce the objects in the smelter in 3D to create their digital twins. These objects are control panels, gutters, ladle vans, oxygen hoses, and oxygen valves. It was also necessary to create realistic graphic effects, such as liquid copper and sparks appearing during burning. Interactions require the user to move around the scene, manipulate objects, and react to processes.

The second developed scenario concerns health and safety training in working at heights (Picture 3).

Picture 3. Working at heights in virtual reality

Source: SIE' internal materials.

As part of the training, three virtual sub-scenarios were prepared, including a simulation of a fall from a height. Participants take on the role of an employee cleaning the crane subgrade at height. They can experience a fall from a height due to non-compliance with health and safety rules and test an action to help a colleague who is hanging on a harness. Participants can train the correct behaviour and procedures for performing work at heights, especially during unexpected dangerous events to develop a set of correct, automatic actions in case of dangerous situations. It takes about half an hour for the participant to undergo all the trainings in this scenario.

Training using both scenarios takes place with the assistance of an OSH instructor and an employee experienced in a given job. They provide the trained employee with comprehensive answers to all questions. They can observe the trainee's actions because a virtual image of the employee is displayed on the training room's wall.

Procedures and data collection

Regarding the second element of the case study protocol, a detailed document review was provided to describe the reasons, goals and content of VR training. It included records, specifications, pictures, briefs, manuals and leaflets. Additionally, interviews with persons responsible for the implementation and conducting of VR on-the-job training in the SIE were conducted. Eighty participants' observations during their initial and periodic obligatory OSH training were conducted. Finally, physical artifacts, meaning VR equipment, were investigated and described above.

Guidelines for analysing data and reporting findings

As mentioned above, data was collected from a variety of sources. Each of them had a focus on the specific part of case study description. It is described in Table 2.

Table 2. Sources of data collection and the focus

Source of data collection	Focus
Scientific literature and national regulations review	Familiarise with state-of-the-art knowledge about OSH training as an essential element of modern management of employee safety and health and the use of VR technology in this area.
Company documentation review	Describe thoroughly the procedure and content of VR on-the-job training, their goals, recipients, planning and implementation processes and incorporation in company's OSH procedures.
Participants' observation	Analyse the attitudes towards VR training, relationships between users and the VR technology, advantages and disadvantages for users (blue-collar workers) while doing the VR training.
Interview with VR training specialist	Acquire in-depth view on how the training idea was developed and applied into OSH standard procedures, how blue-collar workers have been dealing with the technology and what improvements (if any) were applied since the beginning of the VR training project.
VR equipment investigation	Experience physically the same sensations as the participants' experience during the training, and explore the equipment in order to analyse its ergonomics, user-friendliness etc.

Source: own study.

The collection of data from a variety of sources led to an application of the triangulation approach in order to compare and complete the information about the analysed case study.

The answers to the first and second research questions were based mainly on the company's documentation analyses and an interview with the training specialist and compared with the literature review. The main sources of information towards the explanation of the third and fourth research questions were participants' observations and an interview with a training specialist, as well as a VR equipment investigation. Additionally, the analyses were juxtaposed with the findings from the human-VR interaction literature.

The last research question was discussed on the basis of the company's documentation investigation, especially the establishment of strategic and operational goals of OSH and regulations towards the diminution of accidents at work. Additionally, the material from the interview complemented the content of the discussion.

The discussion of stated research questions

Regarding the first research question, the purpose of using OSH training based on VR for SIE blue-collar workers is to increase the effectiveness of on-the-job training, teach employees the code of conduct in particularly hazardous work and develop good habits before starting employment in the natural environment. The most important goal of the training is to create fixed or even automatic behavioural patterns containing complete and accurate sequences of behaviour in hazardous conditions. The result of creating such a pattern of behaviour is the ability to control actions even in situations of high stress and unpredictable environmental conditions. The long-term goal is to shorten the training process for new employees and achieve high performance, low accident rates and downtime. It takes about 2 years to train a trigger to be a confident worker. This is the time needed not only to acquire the necessary skills, but also to experience all possible and unforeseen situations. It is expected that the tested VR training scenario will allow for much faster achievement of these goals.

Considering the effectiveness and efficiency of the VR training on a variety of aspects mentioned in the second research question, the initiative is still in the testing phase, mainly by volunteers, which means that systematic analyses of effectiveness and efficiency based on the analysis of accident reduction, production shortages, and increase in production quality, as well as performance have not been carried out yet.

Currently, training is also not an effective tool for newcomers to increase the pace of skill development in the workplace because, above all, experienced workers voluntarily test the VR training scenarios to express their opinions and feedback. Although systematic surveys of participants' satisfaction or engagement have not been carried out, the volunteers, especially younger ones, expressed their eagerness and engagement during VR training and these positive experiences may also impact their well-being. Additionally VR training allows one to effectively engage the user's muscle memory. The movements that were practised in virtual reality correspond exactly to those activities that are used at work. Thus, the effectiveness of motor coordination required at work in reality is much higher than if the worker operated only on the instructions acquired during theoretical demonstrative training.

Although there is no direct evidence of positive results of VR training on effectiveness or efficiency in OSH areas there were some comparisons conducted in the area of safe behaviour at work. Previous systematic observation of employee behaviour at workplaces revealed that about 11% of blue-collar workers had contributed to dangerous behaviours. These mainly concerned the incorrect use of personal protective equipment (e.g. dust respirators, safety goggles, face shields). These behaviours were increasing the likelihood of accidents at work and occupational diseases. A year after the implementation of VR training, the percentage of dangerous behaviours decreased to 4%, which might indicate the effectiveness of the training in terms of building employee awareness to take care of their own health, as well as raising the level of safety culture in the company. However, it is not known whether it was VR training, as it was one of many tools used for improving the safety culture, along with mandatory OSH training, lectures, the use of tools to increase awareness in the area of occupational safety regarding the correct fitting of personal protective equipment, such as the PORTACOUNT device for checking the tightness of the fit of respiratory protection, and the EARfit device for checking the fit of hearing protection. Resuming the above considerations, more robust and evidence-based investigations must be carried out to assess the level of effectiveness and efficiency of VR training on OSH, performance, development and well-being.

With regard to human-technology relations (third research question), a higher level of engagement and curiosity was observed during VR training in comparison to standard training based on oral explanations presentations and lectures. Workers who participated in both types of training assessed VR sessions as visually attractive, engaging and up-to-date. They appreciated the scenarios as reflected well in the real working conditions of the workstations at the furnace or in heights. The trainees also emphasised that VR training provided a higher increment of self-confidence and self-efficacy right after training compared to traditional training methods. Even though they did not participate in creating scenarios, they were asked about their opinions, concerns and feedback, which are systematically analysed and will influence the future development of this type of training in the company.

The weaknesses of the VR training, mentioned in the fourth research question, were analysed regarding the content and the users' reactions. As for the first one, there is a lack of the sensation of heat (in the real workstation, the temperature in the furnace exceeds 1400 Celsius degrees), however the image and sound are similar in the VR scenario. The controllers are standard in weight so they do not reflect the real weight of the work tools. Finally, the participant is not dressed as in real work when they wear heavy metallising coats to protect against heat and sparks which strongly restricts movements and is uncomfortable. The other types of problems related to VR training were related to negative bodily sensations such as cybersickness (dizziness and problems in keeping balance due to disorders in a labyrinth). Those workers refused further training and resigned from voluntary participation (however, these were -individual cases). It was also noticed that older employees are more resistant to VR-based training. However, their initial fear and hesitation disappear if an appropriate atmosphere is provided during training and more time for instruction.

The described VR training is still in the testing phase, however, plans for the future are prepared. Answering the fifth research question, the company considers transforming other dangerous processes into VR reality, both the entire processes and specific parts of them. It is also considered to train new employees or those returning to their duties after a long break and those who have fallen into a dangerous routine while performing their duties for many years. A special platform for VR training was ordered, a specialised workstation for working at height – it is designed to protect the employee from falling over during the training.

Conclusion

The literature review on the subject shows that the interest in using immersive technologies like Virtual Reality for OSH training is growing every year. Various studies concluded that VR has great potential to be effective for OSH training and can, therefore, complement or replace traditional OSH training methods (Babalola et al., 2023).

The company analysed in this article is characterised by a comprehensive approach to managing employee safety and health. It constantly improves its activities in this area and seeks innovative solutions to prevent or minimise the risks of workers experiencing adverse OSH outcomes, such as injuries, illnesses, and fatalities. In addition to many already implemented activities, the company has introduced VR technology in on-the-job training for employees involved in particularly hazardous work. VR-based training complements the previously applied solutions in the field of OSH training. The project began in 2023 and is currently in the testing phase. However, the conducted case study allows the authors to posit that VR-based OSH training will become a permanent element of the safety culture within the analysed enterprise. Nevertheless, actions are necessary to address the weaknesses identified in this article, with a particular emphasis on assessing the effectiveness of VR applications at each of the four levels: reaction, learning, behaviour, and results (Kirkpatrick, 1994).

The authors wish to emphasise that relying on a single case study to demonstrate the application of VR in occupational safety training might limit the broader applicability of their findings. Although case studies provide deep insights, their unique characteristics often mean that results may not be universally applicable across different industries or within various companies in the smelting sector.

References

Abich, J., Parker, J., Murphy, J.S., Eudy, M. (2021). A Review of the Evidence for Training Effectiveness with Virtual Reality Technology. *Virtual Real*, 25(4), p. 919–933.

Babalola, A., Manu, P., Cheung, C., Yunusa-Kaltungo, A., Bartolo, P. (2023). Applications of Immersive Technologies for Occupational Safety and Health Training and Education: A Systematic Review. *Safety Science*, 166, p. 106214.

Bell, B.S., Tannenbaum, S.I., Kevin Ford, J., Noe, R.A., Kraiger, K. (2017). 100 Years of Training and Development Research: What we Know and Where we Should go. *The Journal of Applied Psychology*, 102(3), p. 305–323.

Benitti, F.B.V. (2012). Exploring the Educational Potential of Robotics in Schools: A Systematic Review. *Computers & Education*, 58(3), p. 978–988.

Burke, M.J., Sarpy, S.A., Smith-Crowe, K., Chan-Serafin, S., Salvador, R.O., Islam, G. (2006). Relative Effectiveness of Worker Safety and Health Training Methods. *American Journal of Public Health*, 96(2), p. 315–324.

Burke, M.J., Salvador, R.O., Smith-Crowe, K., Chan-Serafin, S., Smith, A., Sonesh, S. (2011). The Dread Factor: How Hazards and Safety Training Influence Learning and Performance. *The Journal of Applied Psychology*, 96(1), p. 46–70.

Buttussi, F., Chittaro, L. (2021). A Comparison of Procedural Safety Training in Three Conditions: Virtual Reality Headset, Smartphone, and Printed Materials. *IEEE Transactions on Learning Technologies*, 14(1), p. 1–15.

Cordeiro, A.M., Santos, F., Winkler, I. (2023). Effectiveness of Industrial Training Using Virtual Reality to Mitigate Risks Associated with the Work Environment: A Literature Review. *Blucher Engineering Proceedings*, 10(5), p. 564–571.

De Back, T.T., Tinga, A.M., Louwerse, M.M. (2023). Learning in Immersed Collaborative Virtual Environments: Design and Implementation. *Interactive Learning Environments*, 31(8), p. 5364–5382.

Dhalmahapatra, K., Maiti, J., Krishna, O.B. (2021). Assessment of Virtual Reality Based Safety Training Simulator for Electric Overhead Crane Operations. *Safety Science*, 139, p. 1–13.

Ebneyamini, S., Sadeghi Moghadam, M.R. (2018). Toward Developing a Framework for Conducting Case Study Research. *International Journal of Qualitative Methods*, 17(1), p. 1–11.

EU-OSHA (2020). *OSH Training*. Retrieved from: https://oshwiki.osha.europa.eu/en/themes/osh-training (accessed: 26.12.2023).

EU-OSHA (2023). *Contributing to Occupational Risk Prevention Through Initial and Continuing Training. A Prospective Study to 2030*. Retrieved from: https://oshwiki.osha.europa.eu/en/themes/contributing-occupational-risk-prevention-through-initial-and-continuing-training (accessed: 26.12.2023).

European Commission (2021). *EU Strategic Framework on Health and Safety at Work 2021–2027 Occupational Safety and Health in a Changing World of Work*. Retrieved from: https://eur-lex.europa.eu/legal-content/PL/TXT/?uri=CELEX:52021DC0323 (accessed: 26.12.2023).

Gao, Y., Gonzalez, V.A., Yiu, T.W. (2019). The Effectiveness of Traditional Tools and Computer-aided Technologies for Health and Safety Training in the Construction Sector: A Systematic Review. *Computers & Education*, 138, p. 101–115.

Hamad, A., Jia, B. (2022). How Virtual Reality Technology Has Changed Our Lives: An Overview of the Current and Potential Applications and Limitations. *International Journal of Environmental Research and Public Health*, 19(18), p. 2–14.

Joshi, S., Hamilton, M., Warren, R., Faucett, D., Tian, W., Wang, Y., Ma, J. (2021). Implementing Virtual Reality Technology for Safety Training in the Precast/Prestressed Concrete Industry. *Applied Ergonomics*, 90, p. 1–11.

Kirkpatrick, D.L. (1994). *Evaluating Training Programs: The Four Levels*. California: Berrett-Koehler.

Koźlik, M. (2008). Kompleksowe podejście do bezpieczeństwa pracy. *Przyjaciel Przy Pracy*, 10, p. 28–29.

La Viola, J.J. (2000). A Discussion of Cybersickness in Virtual Environments. *ACM SIGCHI Bulletin*, 32(1), p. 47–56.

Norris, M.W., Spicer, K., Byrd, T. (2019). VIRTUAL REALITY: The New Pathway for Effective Safety Training. *Professional Safety*, 64(6), p. 36–39.

O'Connor, T., Flynn, M., Weinstock, D., Zanoni, J. (2014). Occupational Safety and Health Education and Training for Underserved Populations. *NEW SOLUTIONS: A Journal of Environmental and Occupational Health Policy*, 24(1), p. 83–106.

Pandey, S., Kiran, K., Parhi, S., Singh, A.K., Jha, S.K. (2023). Safety Management in the Era of Emerging Industrial Revolution: The Conceptualisation of Safety 4.0. In: Sharma, R., Shishodia, A., Gupta, A. (Eds.). *Fostering Sustainable Development in the Age of Technologies*. Leeds: Emerald Publishing Limited, p. 239–256.

Perry, C. (1998). Processes of a Case Study Methodology for Postgraduate Research in Marketing. *European Journal of Marketing*, 32 (9–10), p. 785–802.

Priya, A. (2021). Case Study Methodology of Qualitative Research: Key Attributes and Navigating the Conundrums in Its Application. *Sociological Bulletin*, 70(1), p. 94–110.

Ramos, D., Cotrim, T., Arezes, P., Baptista, J., Rodrigues, M., Leitão, J. (2022). Frontiers in Occupational Health and Safety Management. *International Journal of Environmental Research and Public Health*, 19(17), p. 1–5.

Schwarze, A., Kampling, H., Heger, O., Niehaves, B. (2019). Is Virtual Reality the Future of Learning? A Critical Reflection. *Proceedings of the 52nd Hawaii International Conference on System Sciences*, p. 1759–1768.

Shi, F., Ning, H., Chen, L., Dhelim, S. (2024). Cyber-Syndrome: Concept, Theoretical Characterization, and Control Mechanism. *Tsinghua Science and Technology*, 29(3), p. 721–735.

Shiradkar, S., Rabelo, L., Alasim, F., Nagadi, K. (2021). Virtual World as an Interactive Safety Training Platform. *Information*, 12(6), p. 219.

Srinivasan, B., Iqbal, M.U., Shahab, M.A., Srinivasan, R. (2022). Review of Virtual Reality Applications To Enhance Chemical Safety: From Students to Plant Operators. *ACS Chemical Health and Safety*, 29(3), p. 246–262.

Stefan, H., Mortimer, M., Horan, B. (2023). Evaluating the Effectiveness of Virtual Reality for Safety-Relevant Training: A Systematic Review. *Virtual Reality*, 1, p. 1–31.

Strojny, P., Dużmańska-Misiarczyk, N. (2023). Measuring the Effectiveness of Virtual Training: A Systematic Review. *Computers & Education: X Reality*, 2, p. 1–19.

Walsh, K.R., Pawlowski, S.D. (2002). Virtual Reality: A Technology in Need of IS Research. *Communications of the Association for Information Systems*, 8, p. 297–313.

Wohlgenannt, I., Simons, A., Stieglitz, S. (2020). Virtual Reality. *Business and Information Systems Engineering*, 62(5), p. 455–461.

Xu, Z., Zheng, N. (2020). Incorporating Virtual Reality Technology in Safety Training Solution for Construction Site of Urban Cities. *Sustainability*, 13(1), p. 243.

Yin, R.K. (2018). *Case Study Research and Applications*. Sixth Edition. Thousand Oaks, CA: SAGE Publications, Inc.

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