Safety Science 166 (2023) 106214

Contents lists available at ScienceDirect

Safety Science

journal homepage: www.elsevier.com/locate/safety

Review

Applications of immersive technologies for occupational safety and health training and education: A systematic review

Akinloluwa Babalola [a], Patrick Manu [b,*], Clara Cheung [a], Akilu Yunusa-Kaltungo [a], Paulo Bartolo [a]

[a] Department of Mechanical, Aerospace and Civil Engineering, The University of Manchester, Manchester M13 9PL, United Kingdom
[b] School of Architecture and Environment, University of the West of England, Bristol BS16 1QY, United Kingdom

ARTICLE INFO

Keywords:
Augmented reality
Mixed reality
Training and education
Immersive technologies
Virtual reality

ABSTRACT

Immersive technologies (ImTs) have emerged as a viable pathway to address poor occupational safety and health (OSH) performance through training and education of workers. This study aimed to gain a holistic view of the applications of ImTs for OSH training and education. A review of the application of ImTs for OSH training and education is conducted using the preferred reporting items for systematic reviews and *meta*-analysis (PRISMA) approach and bibliometric analysis. This resulted in the evaluation of 67 relevant journal articles collected from Scopus, Web of Science, and Engineering Village. The review revealed that ImTs have been applied for OSH training and education in various industries including transportation, construction, mining, and healthcare. It was also revealed that the OSH hazards addressed by ImT-based training and education include but are not limited to fire, fall, electrical and chemical hazards in order to prevent or reduce injuries, illnesses and fatalities. In addition, it was revealed that one of the benefits of ImTs for OSH training and education is better retention of concepts when compared to conventional training and education. Challenges associated with the use of ImTs for OSH training and education include insufficient display brightness for users to effectively see virtual objects in a brightly luminated environment. Among the recommendations for future work is research into how to develop effective communication methods between trainers and trainees immersed in a virtual environment for trainers to fully understand the difficulties trainees experience in operating the developed ImT-based platform and provide solutions to such difficulties.

1. Introduction

While occupational safety and health (OSH) is paramount across all industries, various industrial sectors have different OSH hazards and outcomes which require intervention. For example, working at heights which involve performing tasks above ground level on a job site (Rubio-Romero et al., 2013) is common in industries such as mining, energy/power and the construction industries with workers prone to falling, thereby likely to cause injuries (HSE, 2014; Rey-Becerra et al., 2021). For instance, in the United Kingdom, in 2021/22 there were 123 worker fatalities, and about 600,000 workers sustained non-fatal injuries. (Health and Safety Executive, 2022a). OSH has therefore become a priority for many countries around the world (Gendler and Prokhorova, 2021). These appalling statistics emphasise the urgency for interventions.

A fundamental objective of any health and safety management initiative is the ability to retain relevant knowledge. Over the years, the realisation of this core objective has been through conventional training and education methodologies, which often require physical interaction and substantial operational costs especially when such trainings need to be repeated multiple times to large cohorts of workers. Subsequently, immersive technologies (ImTs) can provide an effective OSH training and education due to features such as real-time visualisation, risk-free visualisation and an improved rate of learning (Dhalmahapatra et al., 2021). Based on these premises, this study takes a look at the application of ImTs to complement OSH training and education in an attempt to address the ongoing poor OSH performances.

It has been observed from academic literature that training and education is essential to improve OSH performance. For example, a study of 100 accidents by Haslam et al. (2005) revealed that the knowledge/skill of workers on the execution of tasks contributed to 42% of the accidents they examined in the construction industry. The training of

* Corresponding author.
E-mail address: Patrick.Manu@uwe.ac.uk (P. Manu).

https://doi.org/10.1016/j.ssci.2023.106214
Received 29 June 2022; Received in revised form 18 May 2023; Accepted 23 May 2023
Available online 17 June 2023

these workers to expand their knowledge/skills on the execution of these tasks could therefore have resulted in fewer accidents. Another accident causation study by Nkomo et al. (2018) in the forestry industry stated that chainsaw operators are highly prone to injuries and even fatalities as a result of lack of training on saw control as well as the adherence to safe work practices. According to Bourassa et al. (2016), lack of training is one of the main causes of frequent occupational accidents within the manufacturing industry. In addition, within the transportation sector, Shang and Lu (2009) reported that the implementation of OSH training programmes always tend to reduce the number of work-related accidents. Sanmiquel et al. (2018) revealed that providing workers in the mining industry with knowledge on the causes and factors of major OSH hazards will improve the OSH performance of the industry. Similarly, a study by Duarte et al. (2019) revealed that training and education especially for less experienced workers would improve the OSH performance in the mining industry. This could also apply to other industries with OSH training and education used in providing workers in various industries with knowledge on OSH hazards and outcomes. Suitable training on workplace hazards would have prevented fatalities that occur annually due to accidents (Zhao and Lucas, 2015). OSH training which can be described as a range of efforts undertaken to engage trainees with the aim of affecting their motivation, behaviour and attitudes in order to improve health and safety of workers on the job (O'connor et al., 2014) with OSH education referring to school settings has therefore been established as one of the interventions that can be used in addressing OSH challenges in the workplace. This paper therefore focuses on OSH training and education of workers through the use of ImTs, which is considered a vital element of the digitisation scheme of industry 4.0 technologies.

It has been observed from literature that researchers have developed interests in the application of ImTs in training and education across industrial sectors. For example, ImTs have been applied in the transportation sector for the flight training of aviation students (Fussell and Truong, 2020) while Ali et al. (2018) proposed using ImTs for competitive physical training in the military to encourage the military forces to challenge themselves. Furthermore, traditional OSH training and education methods including lectures, seminars, online exercises, and non-interactive videos do not seem to be very effective for knowledge acquisition and retention of OSH trainees (Lovreglio et al., 2021). However, in recent times, there have been advancements in the display technologies, computing power and 3D gaming of ImTs with rapid growth of head-mounted display (HMD)-based ImT systems in the consumer market (Renganayagalu et al., 2021). As it has been stated that ImTs have long been considered as an effective medium for training and education (Pantelidis, 2009), it would be worthwhile to consider the role of ImTs in OSH training and education with the aim to address the shortfalls of the traditional methods of OSH training and education while also improving the industrial OSH performances.

ImTs have been applied for training and education for several years (Buttussi and Chittaro, 2021). The advent of ImTs has driven the growth of its use in various educational contexts globally (Çakiroğlu and Gökoğlu, 2019). ImTs can also be applied for OSH training and education in various industries. For instance, the coal mining industry which consists of dangerous working environment could adopt ImTs for miner safety training and emergency rescue drilling (Li et al., 2020). However, there is an underrepresentation of reviews that render a holistic view of the application of ImTs for OSH training and education in different industrial sectors. Some reviews have been conducted on the application of ImTs, especially virtual reality (VR) and augmented reality (AR) for OSH training and education in various industries. Still, most of these reviews are often individualised owing to their focus on the application of just one or two ImTs for OSH training and education on a particular industry such as the study by Zhong et al. (2021) which was a systematic review on the applications of VR for OSH training in the healthcare sector. Some other reviews have also focused on the use of ImTs for OSH training and education to address a particular OSH hazard such as the study by Rey-Becerra et al. (2021) which conducted a literature review on the effectiveness of virtual safety training on working at heights. Moreover, none of the included articles in this study conducted a bibliometric analysis on the applications of ImTs for OSH training and education which is essential because it contributes to effective research planning and interdisciplinary collaborations. The shortfall of comprehensive academic papers, therefore, makes it difficult for researchers and industry professionals to competently explore as well as ascertain the proficiency of all approaches under all scenarios at a glance. This study thus provides a systematic review and bibliometric analysis of the applications of ImTs which include VR, AR and mixed reality (MR) for the OSH training and education in multiple industries and covering a broad spectrum of OSH hazards.

The research questions that therefore direct this study are:

i. What is the current state of research on the application of ImTs for OSH training and education? In particular, what types of industrial OSH hazards and outcomes are addressed through the use of ImTs for OSH training and education in the academic literature?
ii. What are the challenges/limitations and future research directions regarding the application of ImTs for OSH training and education?

This study begins with an overview of the definitions, concepts and tools pertaining to ImTs. This is followed by a detailed description of the systematic review approach applied for the study. Subsequently, the state of the application of ImTs for OSH training and education in the industry are presented, highlighting the types of OSH hazards and outcomes addressed by the use of ImTs for OSH training and education in various industries. This is then followed by the challenges associated with using ImTs for OSH training and education in the industry with recommendations for future studies on the applications of ImTs for OSH training and education and finally, the conclusion of this study.

2. Background: Definition, concepts and tools of immersive technologies

ImTs consists of VR, AR, and MR (Calvet et al., 2019). VR can be described as a computer-generated environment which allows users to interact with digital images called avatars (Herbst et al., 2021). For further clarity, VR can be described as a computer-generated three-dimensional (3D) simulation of real-world scenarios which allows users, with the aid of electronic devices worn on their body to perceive and interact with the simulated environment (Freina and Ott, 2015; Neguţ et al., 2016). The setup of VR could involve the use of VR HMDs or multiple projected screens which provide an immersive experience of the virtual world, or with the use of a desktop monitor or smartphone which provides non-immersive experience of the virtual world to users (Robertson et al., 1993; Buttussi and Chittaro, 2021). VR produces content that consists of a computer-generated environment or a 360-degree view of digital images which can be viewed with a VR HMD (Araiza-Alba et al., 2021). VR can be seen as a form of ImTs in which computer can be used to sense and track the position and movement of users in a virtual environment and augment the sensing feedback to one or more human senses thereby providing the sense of immersion (Saghafian et al., 2020). In recent times, VR has been used to recreate scenarios such as emergency or risky environment which is difficult to investigate in the real world (Gamberini et al., 2021).

AR can be described as the integration of computerised information and real-world scenarios (Wu et al., 2013; Rodríguez-Abad et al., 2021). AR combines virtual and real objects, aligns them with each other in a real environment, and renders the objects interactively in real-time (Di Serio et al., 2013; Rodríguez-Abad et al., 2021). It can be referred to as a technique for enhancing human perception and information extraction from the virtual environment to the real world (Milgram, 2011; Chu et al., 2018; Fenais et al., 2019).

MR can be described as a simulation that involves blending virtual objects and the real world into a semi-virtualised, mixed environment (Rauh et al., 2021). MR consists of AR which is the enhancement of reality with virtual objects and Augmented Virtuality (AV) which is the enhancement of virtual world with real objects (Rauh et al., 2021). Extended reality (XR) is a broad name for VR, AR and MR and it refers to all real and virtual environment and human–machine interactions generated by computer technology and wearables (Alizadehsalehi et al., 2020). Table 1 provides a better illustration of the differences between the features of the three main types of ImTs. It shows that VR highly immerses its users into a virtual environment that consists of virtual objects/scenarios with minimal real objects/scenarios. On the other hand, users of AR are not totally immersed in a virtual environment and so have some level of interaction with real objects. MR, however, allows its users to have a high interaction with real objects as it provides some level of immersion in the virtual environment. Although ImTs are not new forms of technology, the application of this technology in the industry is embryonic which is because there has only been a routine and vast scale of use of ImTs by the industry and the general public within the last five years (Mora-Serrano et al., 2021). In general, ImTs have been applied for the purpose of training and education, especially in the form of immersive serious games due to its ability to highly engage users (Chittaro and Buttussi, 2015; (Çakiroğlu and Gökoğlu, 2019); Gamberini et al., 2021). Serious games are games developed for training and education on situations that are difficult to replicate in the real world due to safety concerns rather than for entertainment (Giessen, 2015; Feng et al., 2018; Saghafian et al., 2020). An increasing number of organisations have implemented ImTs as the imminent future due to its reduced time for training and infrastructure, reduced labour and operational costs and increased productivity while ensuring the safety of human beings and facilities (Saghafian et al., 2020).

Based on the existing literature on the development of virtual environments, they can be created using computer software such as Unreal engine (Dhalmahapatra et al., 2021), Unity game engine (Matsas and Vosniakos, 2017), Blender software (Isleyen and Duzgun, 2019), Second Life (SL) 3D virtual world platform (Le et al., 2015), OpenSimulator and ActiveWorlds (Çakiroğlu and Gökoğlu, 2019). These computer software operate on modelled objects to develop a virtual environment. Different game engines make use of different programming languages to programme the various virtual objects in a virtual environment. The primary language of Unity game engine is C# (Jiang et al., 2018) while the programming of modelled objects in Unreal game is C++ (Fathima and Aroma, 2019). Some of the software used for the modelling of virtual objects to be uploaded into the different game engines are Autodesk Maya (Khan et al., 2021), Adobe Fuse (Khan et al., 2021), Autodesk Revit (Rahouti et al., 2021) and Google SketchUp (Ouyang et al., 2018). A model can be categorised as low poly mesh which can be developed using modelling tools in Autodesk Maya such as Bevel, Insert Edge loops and Extrude and high poly mesh which cannot be used in game engines as it consumes more computing power from the system (Fathima and Aroma, 2019). However, baking can be used to model low poly mesh objects to appear like high poly mesh objects with texturing software such as Substance Painter 2 (Fathima and Aroma, 2019). The process of the development of a virtual environment therefore involves the sculpting of real world objects with a 3D modelling software which will then undergo texturing which also involves adding of colour to the modelled objects before being uploaded to a game engine to be controlled using a programming language (Fathima and Aroma, 2019). For further clarification, an object modelled into a special player in a virtual environment to represent users of the virtual environment is known as a virtual avatar (Khan et al., 2021).

While the roles of the aforementioned software tools in developing the creation of a typical virtual environment is uncontested, there are also devices that are used for the simulation of the interaction between users and the virtual environment. These devices include keyboard, mouse, wired glove, multidirectional treadmill, joystick, exoskeleton and trackball (Dhalmahapatra et al., 2021). For example, the users of a virtual environment developed with the use of Unity game engine for the training of mine rescue brigades for search and rescue purposes used joysticks for interaction with the virtual environment (Pedram et al., 2021) while trainees used hand controllers on Covid-19 related health and safety skills (Birrenbach et al., 2021).

Table 1
Features of the different types of ImTs (()).

Features	Main Types of ImTs		
	VR	AR	MR
Virtual/Synthetic content level	High	Low	Medium
Real content level	Low	High	High
Interaction level	Low	Medium	High
Immersive level	High	Medium	Medium

adapted from Alizadehsalehi et al., 2020; Khan et al., 2021

3. Methodology

The shortfall of comprehensive academic papers on the application of ImTs for OSH training and education in different industrial sectors makes it difficult for researchers and industry professionals to competently explore as well as ascertain the proficiency of all approaches under all scenarios at a glance. The previous literature reviews that have been identified used systematic review (Zhong et al., 2021), traditional literature review (Afzal and Shafiq, 2021; Rey-Becerra et al., 2021) and critical review (Li, 2018) methodologies. However, the current study adopts the PRISMA-based systematic (SLR) approach and a bibliometric analysis which implies that there is a systematic approach to the definition of keywords, database selection, articles inclusion/exclusion and research timeline, which makes it easier for future researchers to determine the exact contributions as well as limitations of each study. This method links all evidence to the research questions using the clearly defined process which would result in minimal bias, thereby making the findings reliable from which conclusions can be drawn and decisions made (Snyder, 2019).

3.1. Review approach

SLR based on the PRISMA approach was adopted in this study with the aim of obtaining a broad view on the application of ImTs for OSH training and education in several industries. A SLR is a literature review approach which requires considerate efforts to identify and interpret contributions of existing academic studies that relates to the investigated topic, thereby incorporating these studies on a clarity, impartiality and reliability basis (Qiao et al., 2021). The literature search was conducted using three online databases which are Scopus (https://www.scopus.com), Web of Science (https://www.webofknowledge.com) and Engineering Village (https://www.engineeringvillage.com), owing to their technical prowess, diversity and size, especially with regards to technology and OSH. The three online databases were used to ensure the available relevant literature was utilised for this research in order to optimally obtain insights on the field of study and to increase validity of the results. Furthermore, these databases have been chosen because they provide quick access to relevant literature and metrics such as CiteScore metrics which helps track the impact of journals. These are citation databases that extract articles related to the field of study across an extensive range of disciplines. The keywords used for the search were divided into three fields with the first field focusing on the technology, the second field on training and education and the third field on OSH as shown in Fig. 1.

The set of keywords that was applied to verify the title, abstract and keywords of the papers collected from Scopus database is:

(TITLE-ABS-KEY ("Augmented Reality" OR "AR" OR "Virtual Reality" OR "Mixed Reality" OR "MR") AND TITLE-ABS-KEY ("Training" OR

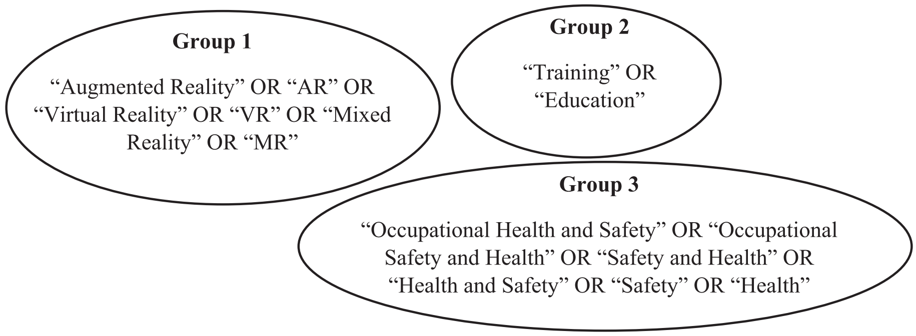

Fig. 1. Keywords for systematic literature review.

"Education") AND TITLE-ABS-KEY ("Occupational Health and Safety" OR "Occupational Safety and Health" OR "Safety and Health" OR "Health and Safety" OR "Safety" OR "Health"))

The set of keywords that was applied to verify the title, abstract and keywords of the papers collected from Web of Science (WoS) database is:

((TI=(("Augmented Reality" OR "AR" OR "Virtual Reality" OR "VR" OR "Mixed Reality" OR "MR") AND ("Training" OR "Education") AND ("Occupational Health and Safety" OR "Occupational Safety and Health" OR "Safety and Health" OR "Health and Safety" OR "Safety" OR "Health"))) OR (AB=(("Augmented Reality" OR "AR" OR "Virtual Reality" OR "VR" OR "Mixed Reality" OR "MR") AND ("Occupational Health and Safety" OR "Occupational Safety and Health" OR "Safety and Health" OR "Health and Safety" OR "Safety" OR "Health"))) OR (AK=(("Augmented Reality" OR "AR" OR "Virtual Reality" OR "VR" OR "Mixed Reality" OR "MR") AND ("Occupational Health and Safety" OR "Occupational Safety and Health" OR "Safety and Health" OR "Health and Safety" OR "Safety" OR "Health")))

The set of keywords that was applied to verify the title, abstract and keywords of the papers collected from Engineering Village (EV) database is:

(((("Augmented Reality" OR "AR" OR "Virtual Reality" OR "VR" OR "Mixed Reality" OR "MR") WN KY) AND (("Training" OR "Education") WN KY)) AND (("Occupational Health and Safety" OR "Occupational Safety and Health" OR "Safety and Health" OR "Health and Safety" OR "Safety" OR "Health") WN KY))

Fig. 2 shows a flowchart that depicts the different stages of the SLR process. The initial search yielded 6,777 publications from Scopus, 2,021 articles from WoS and 6,717 articles from EV databases, making a total of 15,515 articles. The search strings were then limited to journal articles. This is because journal articles are peer-reviewed and provide a more comprehensive information with higher quality when compared to other publication types (Farghaly et al., 2021; Hou et al., 2021). Furthermore, it has been observed that other document types such as conference papers when included in SLR usually complicate the analytical process and yet add very little to the results (Butler and Visser, 2006; (Hosseini, 2018); Wuni et al., 2019). The articles selected must be written in English, and there was no specified timeframe in selecting the relevant articles. After filtering the search string based on predefined inclusion and exclusion criteria, the total number of relevant articles was 7,288 articles, with 3,810, 1,348 and 2,130 articles from Scopus, WoS and EV databases, respectively. These articles were then screened by their titles and abstracts as regards to the relevance of these articles to the scope of this study. The screening of titles and abstracts of these articles filtered out 7,125 articles. For instance, an article by Blankholm and Hansson (2020) which "*aimed to assess the extent of the magnetic resonance (MR)-related incidents by identifying gaps between the results of a national questionnaire and the reported MR- related incidents to a national database, assessing the type of MR-incidents reported and determining if the MR safety education level was sufficient between 2015 and 2017*" was one of many articles that was filtered out due to the lack of relevance of its contents.

Eventually, 116 articles were considered relevant across all databases, with a distribution of 30, 46 and 32 articles from Scopus, WoS and EV databases, respectively. The next stage of the filtration involved use of Mendeley, a reference management system to remove duplicate and triplicate articles. This process revealed 7 duplicates from EV database alone, because it comprises of 4 smaller but distinct databases, namely; Compendex, Inspec, Geobase and Georef. The exclusion of these 7 repeated articles further reduced the outputs from EV to 25 relevant articles and 101 articles in total. Moreover, 5 triplicates from the three databases; 14 duplicates from Scopus and WoS databases; 5 duplicates from Scopus and EV and 5 duplicates from WoS and EV were identified and excluded accordingly. With the aim to enhance clarity and visibility, the Venn diagram shown in Fig. 3 depicts the distribution of the repeated articles across the databases through the intersection points. Fig. 3 shows the importance of using three different scientific databases as more articles were obtained which were not collected in the other databases. For example, in addition to the 30 articles collected in the Scopus database, 37 relevant articles were collected from WoS and EV databases. This shows that efforts have been made to ensure available data has been maximised and the relevant literature has been considered. This would therefore ensure that the conclusions made from this systematic review accurately reflect the extant literature on the subject of inquiry. Once all duplicates and triplicates were removed, 67 relevant papers were retained for further detailed review. The SLR revealed that some previous studies attempted to investigate the application of ImTs (mainly VR, AR and MR) for OSH training and education in various industrial sectors such as fire service (Li and Xiao, 2018), construction industry (Eiris et al., 2020), transportation sector (Chittaro, 2018) and many more. The identified studies attempted to investigate the application of ImTs (mainly VR, AR and MR) for OSH training and education in various industrial sectors by using approaches such as experimental study, simulation (Cha et al., 2012), pilot study (Zhao et al., 2016) and survey (Udeozor et al., 2021). However, a conspicuous insignificant number of reviews renders a holistic view of research activities related to the application of ImTs for the OSH training and education in various industrial sectors. Moreso, the uniqueness of this study is further buttressed because none of the limited numbers of existing reviews are systematic, which makes it more challenging to establish robustness especially with regards to the justifications for the identified relevant articles, search keywords and timelines covered, which are essential for planning future research endeavours.

3.2. Analysis

The initial stage of the analysis entailed observing the bibliometric data which was carried out by the analysis of the frequency of the included articles based on year of publication, title of journal, location of study and research method. The frequency analysis was facilitated by

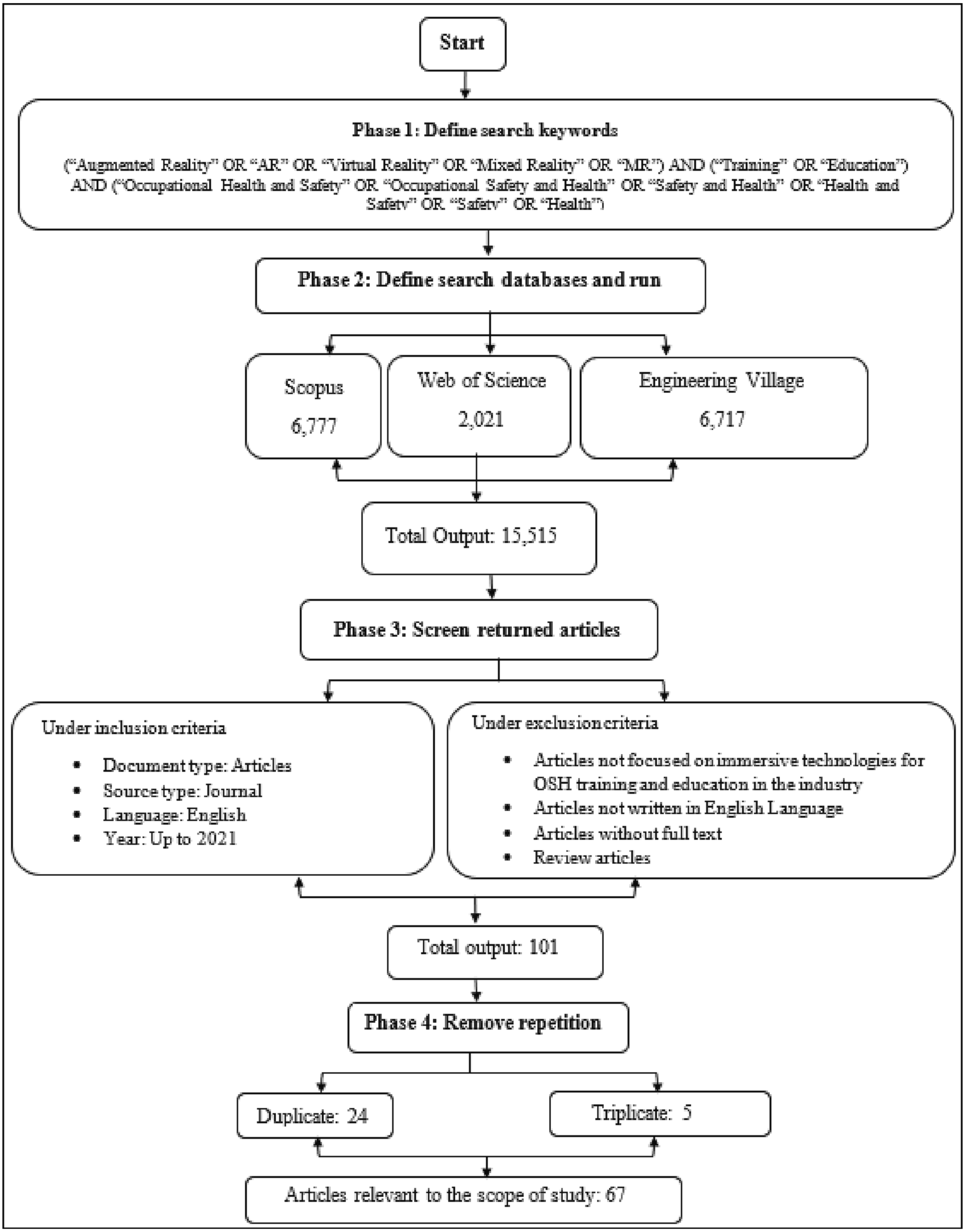

Fig. 2. PRISMA-based SLR flow diagram.

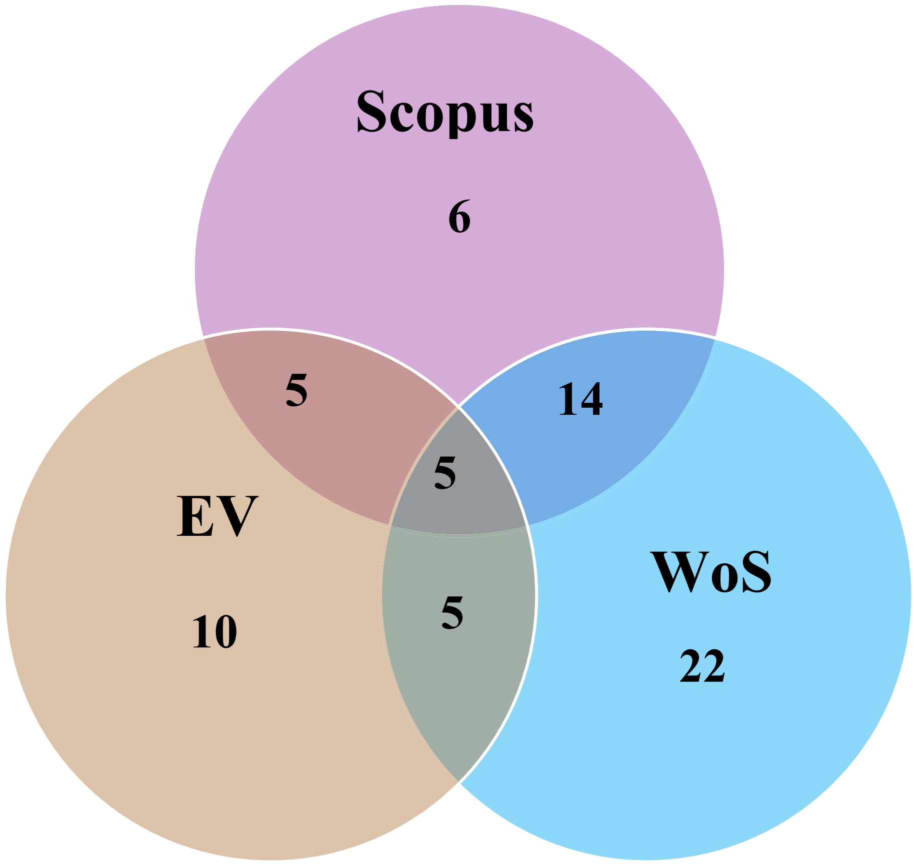

Fig. 3. Venn diagram of the distribution articles across databases.

using an analytic framework (see Table 2) to enable the annotation of the included articles and extraction of relevant information about the research objectives.

For the effective analysis of the included articles, the SLR identified the locations of studies, aims and objectives of the studies, the research methods used by the study, the main findings of the study, other subsets of industry 4.0 technologies used to complement ImTs, the various challenges experienced in the applications of ImTs for OSH training and education and the types of OSH hazards and outcomes addressed by ImTs-based training and education. The SLR further identified future research areas pertaining to the applications of ImTs for OSH training and education.

4. Results and discussions

The results of a bibliometric analysis of the records obtained from Scopus, WoS and EV databases is discussed which shows the trends and patterns in the countries covered by the study, keywords and co-authorships as well as the inter-relationships between these variables. The distributions of publications per year, in different locations of study and the various source titles are also discussed with inferences made from these results. The usefulness of bibliometric analysis, especially regarding SLR, is that it makes the identifying peaks and troughs in data easy. It also enhances researchers to match notable events and to aid research planning.

Table 2
Analytical Framework.

Items
Location (Country) of study
Aims/objectives of study
Main findings/outcomes
Limitations/challenges related to application of ImTs
Type of OSH hazard addressed by ImTs
Type of OSH condition addressed by ImTs
Limitations of the study

4.1. *Bibliometric analysis*

Bibliometric analysis can be defined as the quantitative analysis of written published articles (Ellegaard and Wallin, 2015). Bibliometric analysis is 'useful for deciphering and mapping the cumulative scientific knowledge and evolutionary nuances of well-established fields by making sense of large volumes of unstructured data in rigorous ways' (Donthu et al., 2021, p.1). Software tools developed for visualising the bibliometric analysis of publications include VOSviewer, CiteSpace, Gephi, HiteSpace and BibExcel (Liu, 2013; Akinlolu et al., 2020). The bibliometric analysis of the included articles in this study was conducted using VOSviewer. VOSviewer is a software that is used to create distance-based maps of networks with the level of closeness of nodes being represented by the distance among the nodes (Oraee et al., 2017). This means that the smaller the distance between any two given nodes within the network, the stronger the relationship between the corresponding items and vice versa.

4.1.1. *Mapping of the Co-occurrence of keywords*

The co-occurrence of keywords is conducted to visualise and comprehend the relationships, patterns and intellectual organisations of research themes (van Eck and Waltman, 2014; Jin et al., 2018). The co-occurrence maps were generated based on a combination of keywords extracted from all the databases used for this SLR (i.e. Scopus, WoS, and EV). There are no standard rules for setting the frequency of the occurrence of the keywords (Wuni et al., 2019; Khan et al., 2021). This study, however, adopted best practices suggested by Chen and Song

(2017), Oraee et al. (2017), Jin et al. (2018) and Hosseini et al. (2018) to accomplish the co-occurrence mapping of keywords. Consequently, with the use of fractional counting method, a total of 3,747 keywords were extracted using the fractional counting method. With a minimum number of 5 co-occurrence of keywords, 138 keywords co-occurred, and 9 significant clusters were identified. Fig. 4 shows a network visualisation map of the 9 co-occurring keyword clusters with 70 items, 298 links and a total link strength of 361. The keywords that have distinctly larger nodes than the rest of the keywords include *virtual reality, training, education,* and *simulation.* The size of a keyword reflects the number of times the particular keyword appeared as an author keyword in research articles while keywords that are closely located reveals their co-occurrence in research articles (Wuni, Shen and Osei-Kyei, 2019). Clusters are represented by the colours, and they indicate that the keywords co-occur most frequently. For instance, *technology, military, virtual worlds, virtual environments, safety,* and *serious games* keywords which are represented by the green colour co-occur frequently. This information could act as a guide for researchers in selecting suitable keywords to use in their articles in order to ensure wider indexing and retrieval of articles. The highly frequently co-occurring keywords also align with the keywords used in the literature search conducted in this study.

4.1.2. Mapping of co-authorship

It is essential to analyse and visualise the network of all the authors of the included articles as it has been stated by Wuni et al. (2019) that the collaboration of researchers and institutions can expedite the exchange of knowledge, applications for joint funding and innovations. The analysis and visualisation conducted will help in identifying the leading collaborations in the research on ImTs for OSH training and education. VOSviewer was also used to conduct a network visualisation of co-authorships, and the visualisation which includes the network of the lead authors, and their collaborators is shown in Fig. 5. With the use of VOSviewer, the type of analysis was set to *"co-authorship"* and the unit of analysis was set to *"authors"* while the counting method selected was *"fractional counting"*. The minimum number of documents per author was set to 5 to filter authors that met the threshold. This generated 17,462 authors, including the lead and co-authors, with 11 meeting the set thresholds. The largest set of connected items was 54 items. These connected items yielded 8 clusters, 184 links and a total link strength of 138.5. The overlay visualisation co-authorship network shown in Fig. 5 shows that researchers such as Taylor, D., Darzi, A., Aggarwal, R. and Jones, D. tend to collaborate more frequently. This co-authorship network enhances the ability of researchers to quickly determine answers to essential research planning questions such as "who's doing what, where and when", thereby facilitating future research collaboration.

4.1.3. Mapping of collaborations by country

VOSviewer was again used to recognise the countries that are leading in producing studies that focus on the applications of ImTs for OSH training and education. Similarly, the type of analysis selected was *"co-authorship"* with the unit of analysis set as *"countries"* and the counting method was *"fractional counting"*. Moreover, the minimum number of documents of a country was set to 5 while the minimum number of citations of a country was set to 5. The number of countries detected by VOSviewer software was 151 with 45 meeting the thresholds. The largest set of connected items was, however, 44 items as shown in Fig. 6 which shows the research-active countries in ImTs for OSH training and education. These connected items yielded 9 clusters, 302 links and a total link strength of 346.50. As seen in Fig. 6, bigger nodes represent United States of America (USA), United Kingdom (UK), China and Canada. This indicates that researchers in these are the biggest contributors to the studies on the applications of ImTs for OSH training and

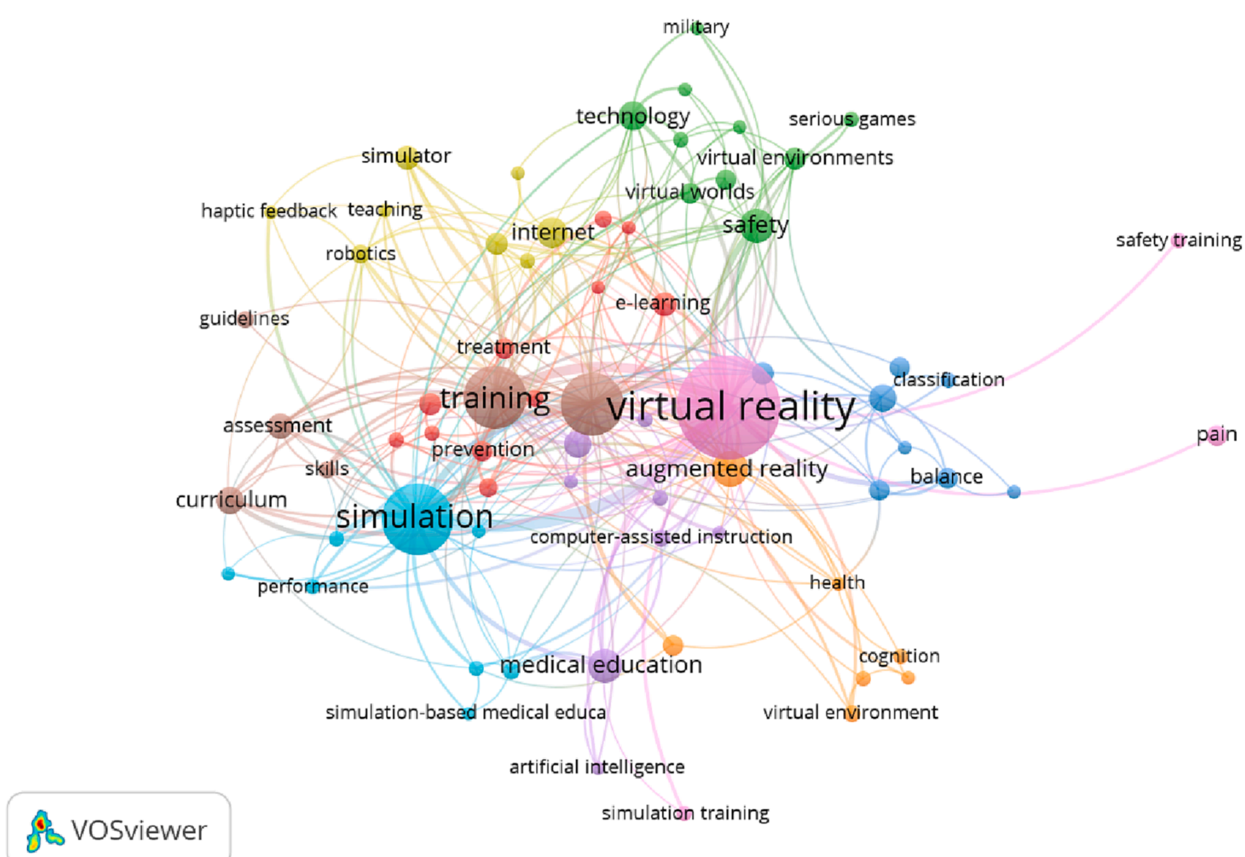

Fig. 4. Network of Co-occurrence of Keywords.

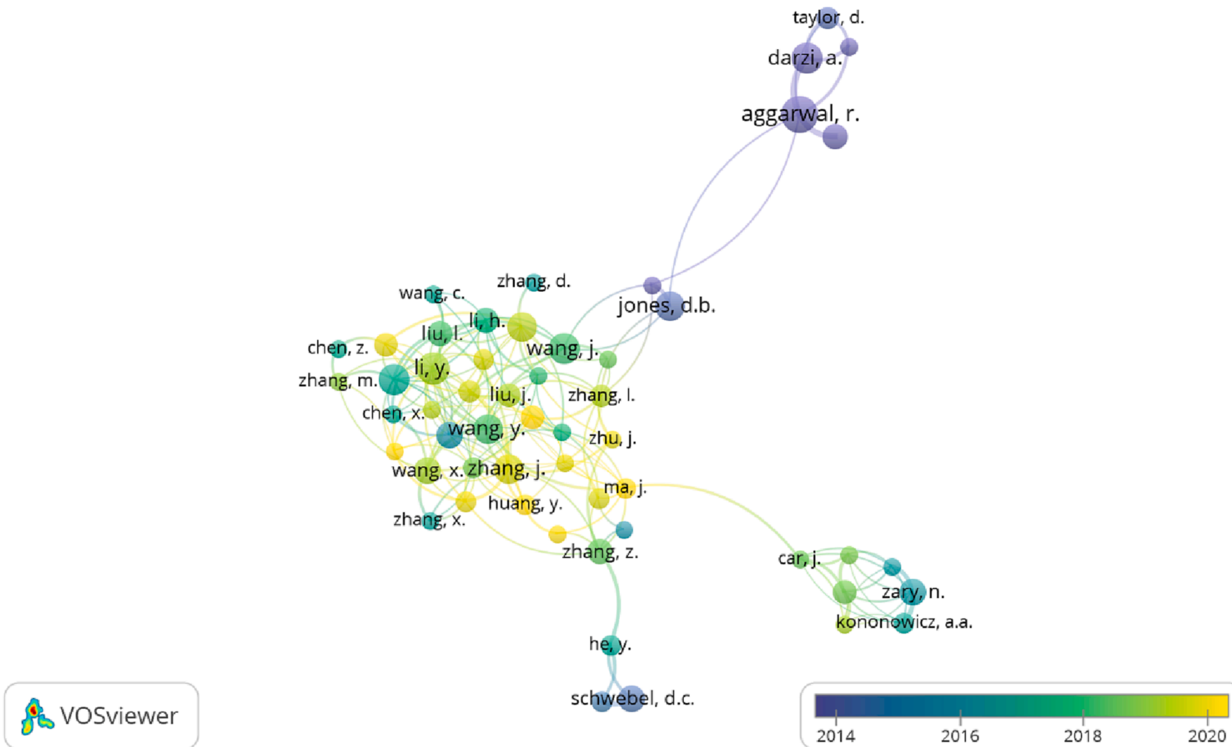

Fig. 5. Network of co-authorships.

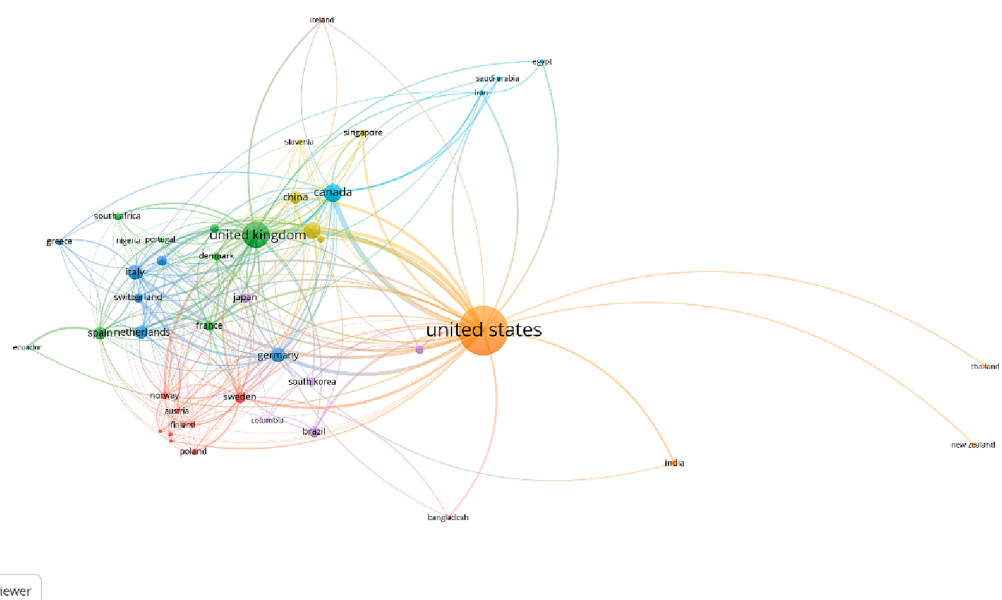

Fig. 6. Network of Collaborations by Country.

education. These findings are however not surprising as it has been noted that there are more research studies from European, American and Asian countries on digital technologies as countries from these continents are ranked the most digitally innovative countries in the world (Martínez-Aires et al., 2018; Vukšić et al., 2018; Aghimien et al., 2020; Akinlolu et al., 2020; Institute of Management, 2021). This is also consistent with the findings of Akinlolu et al. (2020) which highlighted that digitalisation and the adoption of technology in the industry especially for OSH training and education are low in Africa as only Egypt, Nigeria, and South Africa appear in the bibliometric network analysis when compared to the countries in Europe, Asia, and, America.

One of the studies conducted by Guo et al. (2020) in China conceptualised and demonstrated a VR-based safety training system for the training of radiologists and nurses who are fluoroscopically guided interventional (FGI) operators in the avoidance of high radiation areas. It was discovered that the training system enables the visualisation of the radiation field in the FGI suite by the trainees and therefore, they could learn to adjust their postures to minimise their exposure to radiation during FGI procedures (Guo et al., 2020). Fig. 6 shows that there is a high probability that authors or research groups from geographically close countries are more likely to collaborate. However, such practices may not equate to research strength, owing to the fact that expertise are often spread across the globe. Therefore, the essence of the "network of collaboration diagram" depicted by Fig. 6 is to reveal current areas of research intensity, thereby shedding light on other geographic areas where there is limited research intensity. This can in turn inform potential research collaborations between research groups in different locations.

4.1.4. Distribution of publications per year

Fig. 7 shows the number of articles published annually on the application of ImTs for OSH training and education in various industries. It is observed that the number of articles published in 2021 was 19, which was the highest number of articles published as it comprised about 28% of the total number of relevant articles published. It is also observed that in the period from 2012 until 2021, about 94% of the total number of relevant articles identified in this study were published. This means that in general, there has been an increasing interest in research in the scope of this review since 2012, with the highest number of articles published occurring in 2021 where 19 relevant articles were published. As ImTs are subsets of industry 4.0 technologies, the possible reason for this trend could be because of the introduction of industry 4.0 in 2011 during the Hannover Fair in Germany (Xu et al., 2018). However, beginning from 2016, there was a steady rise in research on ImTs for OSH training and education which aligns with the findings of Hall and Takahashi (2017) which revealed that 2016 saw a dawn of a third wave of devices that utilises ImTs especially with large investments and acquisitions of ImTs by tech giants. One of the 19 papers published in 2021 is *"Practical skills training in enclosure fires: An experimental study with cadets and firefighters using CAVE and HMD-based virtual training simulators"* (Grabowski, 2021) which focused on the training in the fire department by comparing a VR system developed with projector and another VR system developed with HMD for the training of firefighters for fighting enclosure fires. The study concluded that although the two VR systems were very useful and accepted, the VR system with HMD was better than the VR system with projector for the training of the firefighters in terms of training assessment, usability, technology acceptance, and spatial presence (Grabowski, 2021). Alternatively, in the construction industry, a significant study amongst the articles published in 2020 titled "Development of virtual reality and stereo-panoramic environments for construction safety training" (Jeelani et al., 2020) which focused on the integration of a virtual construction site developed using 3D computer-aided design models of construction buildings and stereo-panoramic construction site developed using 3D 360 degrees videos captured from real construction sites for training on hazard identification. The study revealed that the immersive environment improved hazard identification and better understanding and management of workplace hazards of the participants which resulted in an increase in training efficiency (Jeelani et al., 2020). Across work domains, a study conducted in 2019 compared the effectiveness of immersive VR-based safety training method to the videos presented in the PowerPoint-based safety training method on novice workers while operating fast-moving machines in the article titled *"Comparing immersive virtual reality and PowerPoint as methods for delivering safety training: Impacts on risk perception, learning, and decision making"* (Leder et al., 2019). The study observed that the difference in the effectiveness of these two methods of training could be due to how engaging or lively the displayed materials are rather than the medium used for presentation (Leder et al., 2019).

4.1.5. Distribution of publications by journal titles

Table 3 presents the distribution of the articles included from all three databases by the titles of journals. The SLR revealed that articles related to the application of ImTs for OSH training and education have been published in 52 journals. However, for brevity, Table 3 only shows the journals with two or more publications. As depicted by Table 3, Safety Science and Advanced Engineering Informatics, are the two journals with the most publications on the application of ImTs for OSH training and education with 7 and 4 relevant articles respectively published in these two journals respectively. The remaining journal titles

Table 3
Distribution of Published Papers by Journal Titles.

Journal Titles	Number of Publications
Safety Science	7
Advanced Engineering Informatics	4
Automation in Construction	2
Computers and Education	2
Journal of the Southern African Institute of Mining and Metallurgy	2
IEEE Transactions on Visualisation and Computer Graphics	2
Sustainability	2
International Journal of Engineering Education	2
Applied Sciences	2
International Journal of Mining Science and Technology	2
Engineering, Construction and Architectural Management	2
Radiation Protection Dosimetry	2
Fire Safety Journal	2

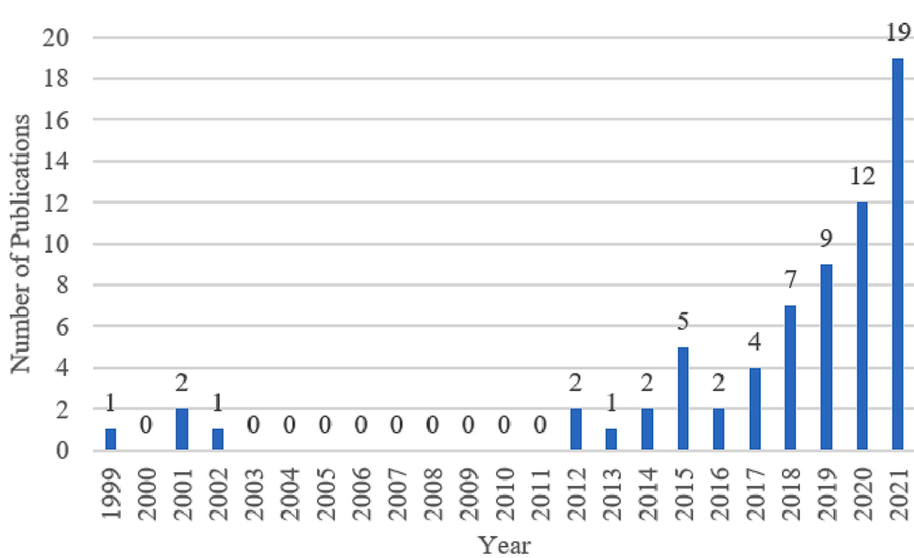

Fig. 7. Distribution of publications per year.

shown in Table 3 contain 2 articles each. Each of these aforementioned journals have published several articles that have contributed to the emergence and understanding of the concepts of technology-driven OSH training and education in various industries. For instance, the article by Dhalmahapatra et al. (2021) in the Safety Science journal evaluated the efficiency and effectiveness of a developed immersive VR-based safety training simulator that is used for the procedural training of electric overhead crane operators. This proved to be effective when compared to the conventional training methods. Overall, the distribution of publications by journals can therefore serve as a guide to researchers in determining suitable outlets for disseminating their studies in the domain of the application of ImTs for OSH training and education.

4.2. Content review

The conventional methods of OSH training such as reading instructions in a manual could be quite challenging for novices to understand, especially for a complicated operation process (Jiang et al., 2018). There are also some circumstances where conducting conventional OSH training is very dangerous. In order to address the drawbacks in the conventional OSH training, OSH training with the use of ImTs can be beneficial due to the safe, efficient and low cost environment of ImT technologies (Xu et al., 2018). The content review component of the systematic review was undertaken in response to following key questions:

- What OSH hazards have been addressed by ImT-based OSH training and education?
- What adverse OSH outcomes have been addressed by ImT-based OSH training and education?
- In which industrial sectors have ImT-based OSH training and education been applied and who are the target users of the training and education?
- What are the challenges/limitations regarding the application of ImTs for OSH training and education?

The above points informed the design of a content review structure (illustrated graphically by Fig. 8) to guide a deductive and systematic detailed review and information extraction from each of the papers (see supplementary material). The synthesis of all the information was subsequently used in framing the contents of the discussion in the following sub-sections, which offer a comprehensive account of the status of application of ImTs for OSH training and education in industries, the related challenges, research gaps, and directions for future research.

4.2.1. Industrial sectors applying ImT-based OSH training and education

Fig. 9 shows the number of articles that have focused on the applications of ImTs across various industrial sectors. Consequently, it is revealed that the construction sector is the industrial sector that has been focused on the most with 25 articles focusing on the applications of ImTs for OSH training and education in the construction industry. This could be because the construction industry is widely known to be one of the most dangerous to work in as data has shown that construction workers are 3 to 4 times more likely to die from accidents at work when compared to other industries (International Labour Organisation, 2015).

An example of a study that focused on ImT-based OSH training and education in the construction industry is the article titled *"Usability of visualisation platform-based safety training and assessment modules for engineering students and construction professionals"* by Bhagwat et al. (2021) which focused on the development of safety training modules for construction professionals using VR. It was then discovered that the construction professionals preferred the VR-based platforms to the traditional methods of OSH training as it provided the opportunity of presenting hazards in a realistic manner without exposing the professionals to risks (Bhagwat et al., 2021).

4.2.2. Types of Occupational safety and Health hazards addressed by immersive technologies

The prominent industrial sectors where studies on ImT-based OSH training an education have been undertaken was also previously shown by Fig. 9. The types of OSH hazards addressed through training and education with the use of ImTs in various industries as revealed by this SLR are fall (Rey-Becerra et al., 2021), fire (Mariš and Fanfarova, 2017), struck-by (Li et al., 2020), chemical (Poyade et al., 2021), and electrical

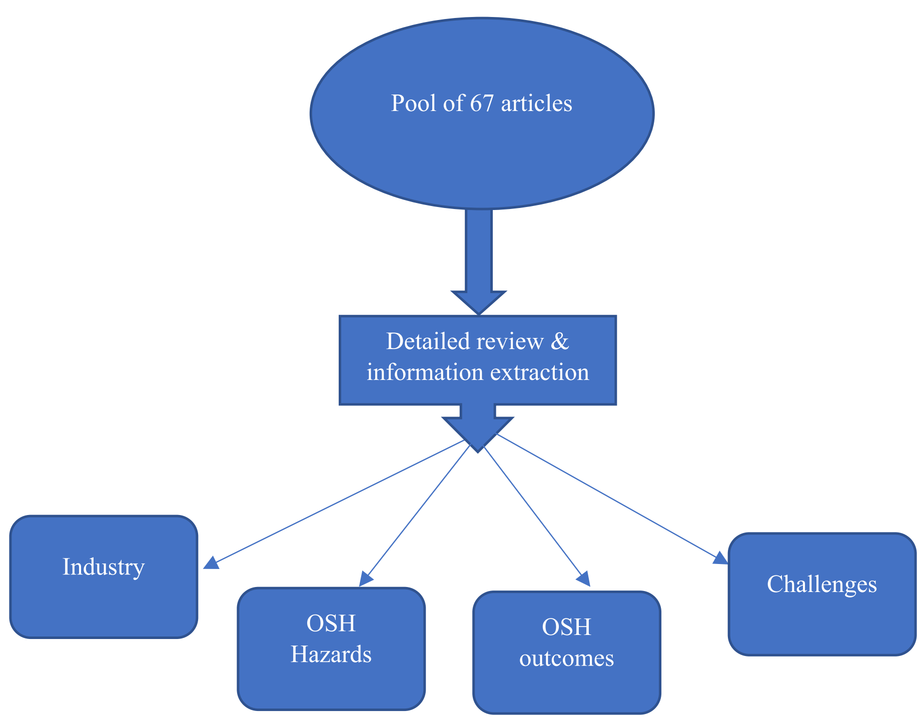

Fig. 8. Systematic content review structure.

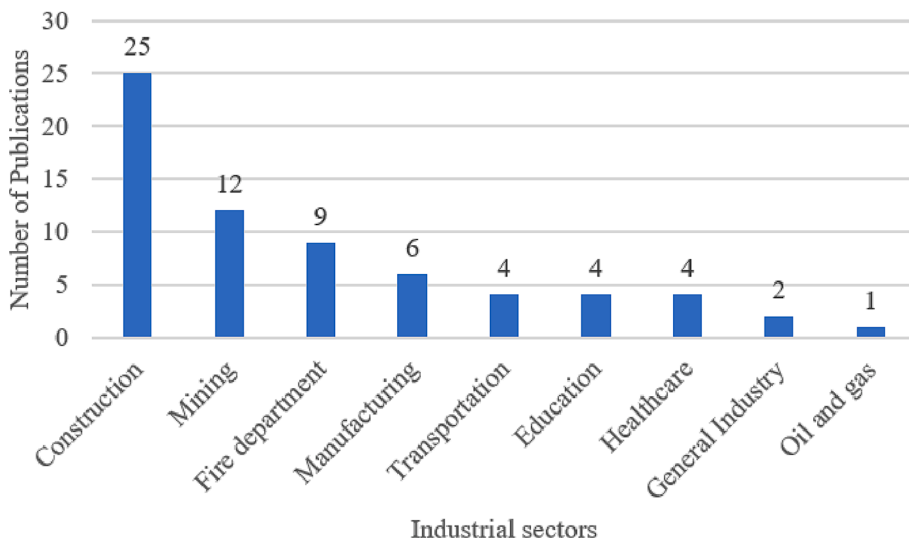

Fig. 9. Distribution of articles per industrial sectors.

hazards (Zhao and Lucas, 2015) as seen in Fig. 10.

As seen in Fig. 10, fire is one of the prominent hazards that literature has focused on in the application of ImTs for training and education. According to Yuan et al. (2012), ImT-based training provides a cost-effective and safe environment for firefighters to practice different fire-fighting techniques. To address fire hazards, Mariš and Fanfarova (2017) proposed the use of simulation tools comprising of ImTs for the training of firefighters due to the high level of risks involved in carrying out their activities. These tools can be applied in the simulation of emergency scenarios to enable firefighters to learn how to react quickly and prepare for fire hazards (Mariš and Fanfarova, 2017). Also addressing fire hazards, the effectiveness of ImTs for safety training in fire emergency situations was examined by Pedram et al. (2021), when safety training for mine rescue brigades was conducted with the use of VR in tackling an escalated fire incident from an underground vehicle and also rescuing a missing miner from the fire incident. The study revealed that the training was considered successful and recommended for use as a complementary solution to the conventional safety training methods in the mining industry such as classroom-based instructive teaching and real-life drills (Pedram et al., 2021). Shiradkar et al. (2021) focused on the knowledge retention, attention, and engagement of workers during the fire safety and emergency evacuation training with the use of VR. While comparing safety training method with the use of VR with that of the slide-based method, it was discovered that participants' long-term knowledge retention, engagement, and attention level were better in VR-based safety training method (Shiradkar et al., 2021). The participants found the VR-based safety training very interesting,

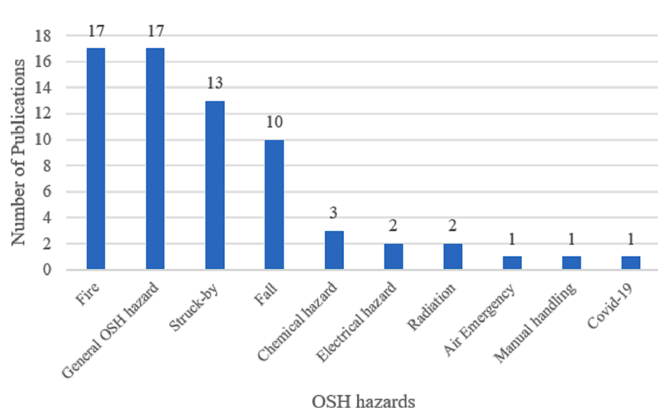

Fig. 10. Distribution of publications with the OSH hazards addressed.

resulting in better long-term knowledge retention than the slide-based safety training method (Shiradkar et al., 2021). Similarly, the knowledge acquisition, retention, and self-efficacy level of hospital workers were evaluated during the fire safety training of the hospital workers on decision making in an emergency situation with VR serious games and slide-based lecture (Rahouti et al., 2021). The study revealed that the VR-based fire safety training could be more effective than the conventional PowerPoint slide-based training in improving the level of knowledge acquired by participants on fire safety rules and the retention level of the acquired knowledge while also improving on the level of self-efficacy of the participants (Rahouti et al., 2021). Fathima and Aroma (2019) proposed a VR-based training system for the fire safety training on the operation steps of fire extinguishers which involves pass, aim, squeeze and sweep (PASS). Fathima and Aroma (2019) are of the view that the training of people on fire safety drills encompassing PASS techniques will not only be effective in knowledge transfer but it will also immensely save time and resources.

Alternatively, to address the risk of getting struck by a suspended load or a moving equipment in a precast/prestressed concrete industry, Joshi *et al.* (2021) developed a VR safety training module for the safety training of construction workers. Joshi *et al.* (2021) then compared the developed VR safety training module to the conventional video-based training method and discovered that the trainees gained more knowledge on safety protocols in the precast/prestressed concrete industry and had higher motivation as the use of the VR safety training module was more engaging than the video safety training method. Dado et al. (2018) investigated the use of VR simulator for safety training of engineering students on the identification of potential hazards during lathe operation such as being struck by a heavy workpiece which could crush feet or fingers. After comparing the outcome of the VR simulator-based safety training with that of in-class lectures based on PowerPoint slide presentations, Dado et al. (2018) discovered that the engineering students who received VR simulator-based safety training did not identify fewer hazards than those who received lecture-based safety training. This indicated the potential of VR as an alternative to the traditional safety training method (Dado et al., 2018). A similar study also compared the effectiveness of VR for safety training with that of an instructional video but focused on addressing the circumstances around getting struck by falling rocks in the mining industry (Liang et al., 2019). To accomplish this, Liang et al. (2019) then developed and evaluated the possible effectiveness of a VR-based serious game for interactive safety training of novice miners and discovered that the VR-based serious game was appealing and memorable to the novice miners and therefore brought about a better training results than the video safety training method.

In another related study, an immersive and interactive multi-player VR-based safety training platform was developed for the training of construction workers in order to prevent fatalities caused by being hit by moving machineries or objects on construction sites (Xu and Zheng, 2021). It was concluded from the results of the study that VR is a useful educational tool and an alternative to conventional safety training methods due to the immersive experience it provides for trainees and its ability to allow trainees visualise hazardous situations without the risk of getting hurt (Xu and Zheng, 2021). Furthermore, a study on a VR-based training programme for the teleoperation of a demolition robot in the construction industry was carried out to understand the effectiveness of VR technology in teaching construction workers how to ensure safety in the working environment (Adami et al., 2021). The VR-based training programme was applied in teaching the demolition robot operators on how to maintain a safe distance while operating the robot to avoid being struck by the robot (Adami et al., 2021). The study then revealed that the VR-based safety training resulted in a significant increase in knowledge acquisition, operational skills, and safety behaviour of the operators especially when compared to in-person training with the robot itself (Adami et al., 2021).

The OSH hazards shown in Fig. 10 might have been focused on by the academic literature possibly because of the statistics of these hazards in various industries. For example, according to Occupational Safety and Health Administration (2022), fall is the leading cause of death in the construction industry, with 351 deaths of the 1,008 deaths caused by fall occurring in the construction industry. The data in the report by Health and Safety Executive (2022b) shows that struck-by and falls from height are among the leading causes of injuries in the manufacturing industry.

4.2.3. *Types of Occupational safety and Health outcomes addressed by immersive technologies*

As shown in Fig. 11, some of the OSH outcomes addressed by ImTs in literature are fatality, illness, and injury. The different types of OSH hazards can impact the safety, health, and wellbeing of workers in different ways in various industries and this study has focused on the different ways ImTs can be used in addressing the various OSH outcomes through training and education. An example is the use of a mobile VR tool to train aircraft passengers in order to prevent fatality in the case of an emergency. The mobile VR tool used for training participants on aviation safety in a study by Chittaro *et al.* (Chittaro, 2018) was compared with the traditional safety briefing card commonly used by airlines for the safety training of passengers on the use of aviation life preserver. Chittaro *et al.* (Chittaro, 2018) then discovered that the mobile VR tool was more engaging than the safety briefing card as the participants understood the instructions better while using the VR tool and they were able to don the life preserver faster with fewer errors while following guidance of the VR tool in comparison to the safety briefing card. Similarly, an HMD-based immersive game was proposed for the aviation safety education of passengers on how to survive a serious aircraft emergency (Chittaro and Buttussi, 2015). Compared to the safety card, the immersive VR setup was more engaging and fear-arousing than the safety card method and the users of the VR setup acquired more knowledge that was maintained after one week, unlike the knowledge loss from users of the safety card (Chittaro and Buttussi, 2015). Another way of preventing fatality with the use of ImTs for safety training is the use of a developed multi-level VR-based training system for the safety training of workers on safety awareness in order to prevent fatalities arising from being struck by the movement of heavy equipment on construction sites such as excavator in a study reported by Xu and Zheng (2021). Based on the outcome of the study, it was concluded that VR can be very useful as an educational tool and it can also be a suitable replacement for conventional safety training methods especially as the trainees were impressed with the ability of the VR-based system to visualise hazardous scenarios without posing any form of risk to the trainees (Xu and Zheng, 2021).

Guo et al. (2020) conceptualised and demonstrated VR-based radiation safety training system with the aim of providing radiologists and nurses safety training on FGI procedures in order to reduce the risk of getting cancer by the FGI operators. It was then observed that the VR-based radiation safety training system could effectively train FGI operators on how to avoid high radiation areas or adjust their postures to minimise their exposure to radiation during FGI procedure (Guo et al., 2020). Another closely related study explored the effectiveness of an immersive VR simulation on the training of health personnel on hand hygiene, nasopharyngeal swab taking, and proper donning/doffing of PPEs to prevent Covid-19 (Birrenbach et al., 2021). There was, however, no significant difference in the effectiveness of VR simulation on trainees on hand disinfection and the donning/doffing of PPEs while there was improvement in nasopharyngeal swab taking after undergoing training with VR simulation when compared with the traditional printed instructions and local instructions video on Covid-19 related skills (Birrenbach et al., 2021).

Safety training given via immersive VR was compared with the safety training conducted via PowerPoint presentation in their effects on risk perception and decision making in order to avoid injuries while using a pillar power drill (Leder et al., 2019). It was noticed that although the VR condition did not increase knowledge retention, it slightly increased

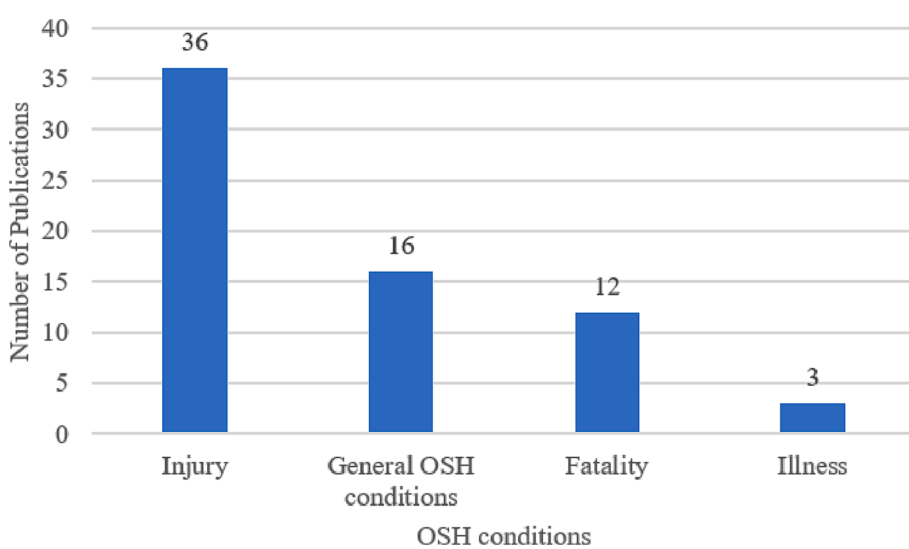

Fig. 11. Distribution of publications with the OSH outcomes addressed.

the ability to identify hazards in a pillar power drill while the decision making of users of the VR-based system was less risk-averse than the decision making of others (Leder et al., 2019).

4.2.4. Challenges involved in application of immersive technologies for OSH training and education

Owing to the ability of ImTs to transfer knowledge without necessarily exposing participants to real-life operational hazards, ImTs have the potential to revolutionise OSH training and education in various industries. However, just as it is with every technology or initiative, some challenges associated with ImTs have been raised by different studies, of which the notable ones are discussed here.

The current HMDs for consumer use are not designed for prolonged usage for educational settings but are rather designed for entertainment and media consumption and so it is not possible to use ImTs for long duration training and education (Renganayagalu et al., 2021). ImTs have had very limited use for training and education purposes as its incorporation as a teaching technology is recent (Rodríguez-Abad et al., 2021). Furthermore, ImTs could be seen to be unsuitable for training and education purposes due to the different learning styles of trainees, gaming competencies and disabilities while gameplay could also be a form of distraction to trainees rendering it ineffective for learning (Udeozor et al., 2021). Furthermore, the development of ImT simulations is time consuming, expensive (Le, 2015; Renganayagalu et al., 2021) and it requires a lot of computing power (Adami et al., 2021) and there is lack of available expertise for the development of ImT-based interactive contents (Rodríguez-Abad et al., 2021). Besides, the use of HMDs for a long time could cause simulation sickness with symptoms such as dizziness, headache, and nausea (Dado, 2018; Xu, 2018).

Another challenge has to do with the difficulty in identifying how trainees will react in case of a real emergency in order to measure knowledge transfer after training. Even though trainees can visualise and practice fire safety procedures in a risk-free virtual environment, it is difficult to ascertain their reactions in actual emergencies (Shiradkar et al., 2021) as for instance, it is not feasible to have emergency situations such as real fire to assess the effectiveness of the training sessions (Saghafian et al., 2020).

It has also been observed that users of ImTs usually face difficulties in the handling of devices such as difficulty in the adjusting of glasses, instability in the images projected onto the screen, the need to keep their head still and many more (Rodríguez-Abad et al., 2021). Users of ImTs could become so used to the virtual world while using HMDs during training sessions that they forget the real world (Liang et al., 2019). It has also been observed that poor image quality can be a challenge to the use of ImTs for OSH training and education as participants could see individual pixels on the display of HMDs (Eiris et al., 2020). The visualisation method used by ImTs which involves amplifying sections of images within a virtual environment leads to lower image quality since the projected areas are displayed at higher resolution with lower pixel densities (Eiris et al., 2020). Moreover, the maximum display brightness might be insufficient for users to effectively see virtual objects in a brightly luminated environment especially due to see-through displays used in HMDs such as Microsoft HoloLens (Rauh et al., 2021). Another challenge is the lack of effective communication methods between trainers and trainees immersed in a virtual environment which is necessary as trainers need to fully understand the difficulties trainees experience during the use of ImTs and provide solutions to such difficulties with the appropriate hardware and/or software tools.

5. Conclusions

This study conducted a comprehensive SLR on the applications of ImTs for OSH training and education. The SLR covered bibliometric analysis and content review of 67 articles related to the applications of ImTs for OSH training and education. Among other things, the bibliometric analysis revealed a year-on-year growth in research publications since 2016, and therefore signifying a trend of growing research intensity in the subject of ImT-based OSH training and education. Also, geographic locations with high research intensity in the subject include USA, UK, China, and Canada, while there is generally relatively low research intensity in the subject in locations such as countries in Africa and the Middle East. The content review interrogated: the industrial context of application of ImTs for OSH training and education; the OSH hazards addressed; the OSH outcomes addressed; and the challenges in relation to ImTs for OSH training and education. The content review revealed that various studies have been conducted on the applications of ImTs for OSH training and education in various industries such as the mining industry, construction industry, healthcare sector and others, however, the industry with the highest research intensity is the construction industry, and this could be attributable to the construction industry's unenviable reputation of being one of the most dangerous industries globally. Regarding OSH hazards addressed, the review showed that while studies have focused on the applications of ImTs-based OSH training and education in addressing different OSH hazards such as fire, chemical, fall and water hazards, there has been a greater focus on fire, struck-by and fall. The content review also revealed that ImTs can be used for the OSH training and education of workers in order to prevent or minimise the risks of workers experiencing adverse OSH outcomes such as injuries, illnesses and fatalities. It has been revealed from the literature that generally, application of ImTs has had a positive effect on OSH training and education.

Various studies concluded that ImTs have great potential to be effective for OSH training and education and it can therefore be used to complement or replace traditional OSH training and education methods. In spite of the utility of ImTs for OSH training, there are also some drawbacks some of which include the long duration and expensive cost it takes for the development and the implementation of ImTs for OSH training and education, the feeling of dizziness, nausea and headache by users of HMDs and also the difficulty in the handling of devices used for the implementation of ImTs by users.

6. Gaps in existing body of knowledge

Some limitations to the studies conducted on the applications of ImTs for OSH training and education were observed. A common limitation observed in various studies was the sample size as studies were conducted with relatively small sample size (e.g. Dado et al., 2018; Bhagwat et al., 2021; Joshi et al., 2021). Moreover, the large difference in the number of males and females participating in training sessions would make it difficult to investigate the gender differences in the evaluation of ImT-based training (Saghafian et al., 2020). In addition, most of the papers focused on training to address occupational safety with very few looking at workplace illnesses. Another limitation is the one day completion time pressure of the training sessions which resulted in short surveys and very limited time for interviews (Saghafian et al., 2020). Although, it is likely that the effects of training will persist through the continuous training of learned concepts, the long-term impacts of the safety training sessions with the use of ImTs is not evaluated (Jeelani et al., 2020). In addition, some studies on the use of ImTs for safety training were conducted on students (as test subjects) with a likelihood of variation of results when conducting training sessions on workers/industry practitioners (Eiris, 2020; Jeelani et al., 2020)(). The study participants on aviation safety training had little to no experience travelling by aircraft and therefore were not exposed to safety brief cards or demonstrations from flight attendants (Chittaro, 2018).

There has also been no study that focused on comparing the effectiveness of ImTs for safety training in the mining industry on college students, teachers, and industry practitioners such as miners. There has also been no study that focused on comparing the effectiveness of VR, AR, and MR on safety training in various industries such as the transportation sector or manufacturing industry. Finally, the conventional methods used to test the performance of ImTs such as questionnaires could have its shortcomings as trainees might not always fill in the correct answers. Moreover, there has been limited focus on occupational health training with ImTs. There has also been limited focus on the applications of ImTs for OSH training in some industries such as agriculture although OSH from several countries (e.g. UK and USA) shows that the agricultural sector is a high-risk sector accounting for high number of fatalities and injuries (Health and Safety Executive, 2021; U. S. Department of Labors, 2021).

7. Future research considerations for ImTs on OSH training and education in the industry

- It is also recommended that research should be conducted to compare the effectiveness of ImTs for safety training in the mining industry on college students, teachers, and industry practitioners such as miners. Further research could also be conducted to compare the effectiveness of VR, AR, and MR on safety training in the various industries such as in the transportation sector or fire department.
- Future research could focus on developing tools for substituting the conventional methods of the performance evaluation of ImTs such as questionnaires. These alternative tools could include other industry 4.0 technologies such as internet of things and machine learning algorithms and compare the effectiveness of the use of these developed performance assessment tools with that of the use of questionnaires.
- Further work should be done to investigate the causes of simulation sickness involved with the use of ImTs and proffer possible ways to eradicate or reduce simulation sickness. Moreover, larger sample sizes could be used to increase the effect of the study and the development of a possible solution to simulation sickness, especially as the sample sizes has also been a common limitation observed in literature.
- It is also recommended that an investigation should be conducted on how to develop effective communication methods between trainers and trainees immersed in a virtual environment in order for trainers to fully understand the difficulties trainees experience and provide solutions to such difficulties with the appropriate hardware and/or software tools.
- More research could focus on applying ImTs for training to address occupational health hazards. In addition, more research could focus on applying ImTs for training to address prevalent OSH hazards and outcomes in the industrial sectors that have been identified to have limited research such as the agricultural sector.

CRediT authorship contribution statement

Akinloluwa Babalola: Writing – review & editing, Writing – original draft, Methodology, Investigation, Formal analysis, Conceptualization. **Patrick Manu:** Writing – review & editing, Supervision, Project administration, Methodology, Investigation, Formal analysis, Conceptualization. **Clara Cheung:** Writing – review & editing, Supervision, Methodology, Investigation, Formal analysis, Conceptualization. **Akilu Yunusa-Kaltungo:** Writing – review & editing, Supervision, Methodology, Investigation, Formal analysis, Conceptualization. **Paulo Bartolo:** Writing – review & editing, Supervision, Methodology, Investigation, Formal analysis, Conceptualization.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ssci.2023.106214.

References

Adami, P., et al., 2021. Effectiveness of VR-based training on improving construction workers' knowledge, skills, and safety behavior in robotic teleoperation. Advanced Engineering Informatics 50 (September). https://doi.org/10.1016/j.aei.2021.101431.

Afzal, M., Shafiq, M.T., 2021. Evaluating 4d-bim and vr for effective safety communication and training: A case study of multilingual construction job-site crew. Buildings. https://doi.org/10.3390/buildings11080319.

Aghimien, D.O., et al., 2020. Mapping out research focus for robotics and automation research in construction-related studies: A bibliometric approach. Journal of Engineering, Design and Technology 18 (5), 1063–1079. https://doi.org/10.1108/JEDT-09-2019-0237.

Akinlolu, M., et al., 2020. A bibliometric review of the status and emerging research trends in construction safety management technologies. International Journal of Construction Management 1–13. https://doi.org/10.1080/15623599.2020.1819584.

Ali, S.F. et al. (2018) 'Virtual reality as a tool for physical training', 2017 1st International Conference on Latest Trends in Electrical Engineering and Computing Technologies, INTELLECT 2017, 2018-Janua, pp. 1–6. 10.1109/INTELLECT.2017.8277617.

Alizadehsalehi, S., Hadavi, A., Huang, J.C., 2020. 'From BIM to extended reality in AEC industry'. Automation in Construction 116. https://doi.org/10.1016/j.autcon.2020.103254.

Araiza-Alba, P., et al., 2021. (2021) 'The potential of 360-degree virtual reality videos to teach water-safety skills to children'. Computers and Education 163. https://doi.org/10.1016/j.compedu.2020.104096.

Bhagwat, K., Kumar, P., Delhi, V.S.K., 2021. Usability of Visualisation Platform-Based Safety Training and Assessment Modules for Engineering Students and Construction Professionals. Journal of Civil Engineering Education 147 (2), 04020016. https://doi.org/10.1061/(asce)ei.2643-9115.0000034.

Birrenbach, T., et al., 2021. Effectiveness and utility of virtual reality simulation as an educational tool for safe performance of covid-19 diagnostics: Prospective, randomized pilot trial. JMIR Serious Games 9 (4), 1–14. https://doi.org/10.2196/29586.

Blankholm, A.D., Hansson, B., 2020. Incident reporting and level of MR safety education: A Danish national study. Radiography 26 (2), 147–153. https://doi.org/10.1016/j.radi.2019.10.007.

Bourassa, D., Gauthier, F., Abdul-Nour, G., 2016. Equipment failures and their contribution to industrial incidents and accidents in the manufacturing industry. International Journal of Occupational Safety and Ergonomics 22 (1), 131–141. https://doi.org/10.1080/10803548.2015.1116814.

Butler, L., Visser, M.S., 2006. Extending citation analysis to non-source items. Scientometrics 66 (2), 327–343. https://doi.org/10.1007/s11192-006-0024-1.

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), 1–15. https://doi.org/10.1109/TLT.2020.3033766.

Calvet, L., Bourdin, P. and Prados, F. (2019) 'Immersive technologies in higher education: Applications, challenges, and good practices', in *Proceedings of the 2019 3rd International Conference on Education and E-Learning*, pp. 95–99. 10.1145/3371647.3371667.

Çakiroğlu, Ü., Gökoğlu, S., 2019. A Design Model for Using Virtual Reality in Behavioral Skills Training. Journal of Educational Computing Research 57 (7), 1723–1744. https://doi.org/10.1177/0735633119854030.

Çakiroğlu, Ü., Gökoğlu, S., 2019. Development of fire safety behavioral skills via virtual reality. Computers and Education 133 (January), 56–68. https://doi.org/10.1016/j.compedu.2019.01.014.

Cha, M., et al., 2012. A virtual reality based fire training simulator integrated with fire dynamics data. Fire Safety Journal 50, 12–24. https://doi.org/10.1016/j.firesaf.2012.01.004.

Chittaro, L., Buttussi, F., 2015. Assessing knowledge retention of an immersive serious game vs. A traditional education method in aviation safety. IEEE Transactions on Visualisation and Computer Graphics 21 (4), 529–538. https://doi.org/10.1109/TVCG.2015.2391853.

Chittaro, L., et al., 2018. 'Safety knowledge transfer through mobile virtual reality: A study of aviation life preserver donning'. Safety Science 102, 159–168. https://doi.org/10.1016/j.ssci.2017.10.012.

Chu, M., Matthews, J., Love, P.E.D., 2018. (2018) 'Integrating mobile Building Information Modelling and Augmented Reality systems: An experimental study'. Automation in Construction 85, 305–316. https://doi.org/10.1016/j.autcon.2017.10.032.

Dado, M., et al., 2018. The Application of Virtual Reality for Hazard Identification Training in the Context of Machinery Safety: A Preliminary Study. Manufacturing Technology 18 (5), 732–736. https://doi.org/10.21062/ujep/168.2018/a/1213-2489/mt/18/5/732.

Dhalmahapatra, K., Maiti, J., Krishna, O.B., 2021. Assessment of virtual reality based safety training simulator for electric overhead crane operations. Safety Science 139 (March). https://doi.org/10.1016/j.ssci.2021.105241.

Di Serio, Á., Ibáñez, M.B., Kloos, C.D., 2013. Impact of an augmented reality system on students' motivation for a visual art course. Computers and Education 68, 586–596. https://doi.org/10.1016/j.compedu.2012.03.002.

Donthu, N., et al., 2021. How to conduct a bibliometric analysis: An overview and guidelines. Journal of Business Research 133 (March), 285–296. https://doi.org/10.1016/j.jbusres.2021.04.070.
Duarte, J., Baptista, J. and Marques, A. (2019) 'Occupational Accidents in the Mining Industry—A Short Review', in Occupational and Environmental Safety and Health. Springer, pp. 61–69. 10.1007/978-3-030-14730-3_83.
Eiris, R., et al., 2020. Safety immersive storytelling using narrated 360-degree panoramas: A fall hazard training within the electrical trade context. Safety Science 127 (January). https://doi.org/10.1016/j.ssci.2020.104703.
Eiris, R., Gheisari, M., Esmaeili, B., 2020. (2020) 'Desktop-based safety training using 360-degree panorama and static virtual reality techniques: A comparative experimental study'. Automation in Construction 109. https://doi.org/10.1016/j.autcon.2019.102969.
Ellegaard, O., Wallin, J.A., 2015. The bibliometric analysis of scholarly production: How great is the impact? Scientometrics 105 (3), 1809–1831. https://doi.org/10.1007/s11192-015-1645-z.
Farghaly, K. et al. (2021) 'Digital information technologies for prevention through design (PtD): a literature review and directions for future research', Construction Innovation [Preprint]. 10.1108/CI-02-2021-0027.
Fathima, S.A., Aroma, J., 2019. Simulation of fire safety training environment using immersive virtual reality. International Journal of Recent Technology and Engineering 7 (4), 347–350.
Fenais, A., et al., 2019. Integrating geographic information systems and augmented reality for mapping underground utilities. Infrastructures 4 (4). https://doi.org/10.3390/infrastructures4040060.
Feng, Z., et al., 2018. Immersive virtual reality serious games for evacuation training and research: A systematic literature review. Computers and Education 127 (May), 252–266. https://doi.org/10.1016/j.compedu.2018.09.002.
Freina, L. and Ott, M. (2015) 'A literature review on immersive virtual reality in education: State of the art and perspectives', *Proceedings of eLearning and Software for Education (eLSE)(Bucharest, Romania, April 23–24, 2015)*, (July), p. 8.
Fussell, S.G., Truong, D., 2020. Preliminary results of a study investigating aviation student's intentions to use virtual reality for flight training. International Journal of Aviation, Aeronautics, and Aerospace 7 (3). https://doi.org/10.15394/ijaaa.2020.1504.
Gamberini, L., et al., 2021. Designing "Safer Water". A Virtual Reality Tool for the Safety and the Psychological Well-Being of Citizens Exposed to the Risk of Natural Disasters. Frontiers in Psychology 12 (June), 1–12. https://doi.org/10.3389/fpsyg.2021.674171.
Gendler, S., Prokhorova, E., 2021. Risk-based methodology for determining priority directions for improving occupational safety in the mining industry of the arctic zone. Resources 10 (3), 1–14. https://doi.org/10.3390/resources10030020.
Giessen, H.W., 2015. Serious Games Effects: An Overview. Procedia - Social and Behavioral Sciences 174 (November), 2240–2244. https://doi.org/10.1016/j.sbspro.2015.01.881.
Grabowski, A., 2021. Practical skills training in enclosure fires: An experimental study with cadets and firefighters using CAVE and HMD-based virtual training simulators. Fire Safety Journal 125 (September). https://doi.org/10.1016/j.firesaf.2021.103440.
Guo, Y., et al., 2020. Conceptual design and preliminary results of a vr-based radiation safety training system for interventional radiologists. Radiation Protection Dosimetry 190 (1), 58–65. https://doi.org/10.1093/rpd/ncaa082.
Hall, S. and Takahashi, R. (2017) 'Augmented and virtual reality: The promise and peril of immersive technologies', *McKinsey&Company*, (October), p. 9. Available at: https://www.mckinsey.com/industries/technology-media-and-telecommunications/our-insights/augmented-and-virtual-reality-the-promise-and-peril-of-immersive-technologies.
Haslam, R.A., et al., 2005. Contributing factors in construction accidents. Applied Ergonomics 36 (4 SPEC. ISS.), 401–415. https://doi.org/10.1016/j.apergo.2004.12.002.
Health and Safety Executive (2021) *Statistics - Industries*. Available at: https://www.hse.gov.uk/statistics/industry/index.htm (Accessed: 4 June 2022).
Health and Safety Executive (2022a) *Health and safety at work Summary statistics for Great Britain 2022*, *Health and Safety Executive*. Available at: chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://www.hse.gov.uk/statistics/overall/hssh2122.pdf.
Health and Safety Executive (2022b) *Manufacturing statistics in Great Britain, 2022*. Available at: https://www.hse.gov.uk/statistics/industry/manufacturing.pdf.
Herbst, R., et al., 2021. A virtual reality resident training curriculum on behavioral health anticipatory guidance: Development and usability study. JMIR Pediatrics and Parenting 4 (2), 1–12. https://doi.org/10.2196/29518.
Hosseini, M.R., et al., 2018. 'Critical evaluation of off-site construction research: A Scientometric analysis'. Automation in Construction 87, 235–247. https://doi.org/10.1016/j.autcon.2017.12.002.
Hou, L., et al., 2021. Literature review of digital twins applications in construction workforce safety. Applied Sciences (Switzerland) 11 (1), 1–21. https://doi.org/10.3390/app11010339.
HSE (2014) 'Working at Height', *A Quick Guide to Health and Safety*, pp. 109–114. 10.1016/b978-1-84569-499-9.50013-x.
Institute of Management (2021) *World Digital Competitiveness Rankings - IMD*. Available at: https://www.imd.org/centers/world-competitiveness-center/rankings/world-digital-competitiveness/ (Accessed: 31 March 2022).
International Labour Organisation (2015) *Construction: a hazardous work*, *International Labour Organisation*. Available at: https://www.ilo.org/safework/areasofwork/hazardous-work/WCMS_356576/lang–en/index.htm (Accessed: 3 June 2022).
Isleyen, E., Duzgun, H.S., 2019. Use of virtual reality in underground roof fall hazard assessment and risk mitigation. International Journal of Mining Science and Technology 29 (4), 603–607. https://doi.org/10.1016/j.ijmst.2019.06.003.
Jeelani, I., Han, K., Albert, A., 2020. Development of virtual reality and stereo-panoramic environments for construction safety training. Engineering, Construction and Architectural Management 27 (8), 1853–1876. https://doi.org/10.1108/ECAM-07-2019-0391.
Jiang, M., et al., 2018. A game prototype for understanding the safety issues of a lifeboat launch. Virtual Reality 22 (2), 137–148. https://doi.org/10.1007/s10055-018-0334-7.
Jin, R., et al., 2018. A holistic review of off-site construction literature published between 2008 and 2018. Journal of Cleaner Production 202, 1202–1219. https://doi.org/10.1016/j.jclepro.2018.08.195.
Joshi, S., et al., June 2020. (2021) 'Implementing Virtual Reality technology for safety training in the precast/ prestressed concrete industry'. Applied Ergonomics 90. https://doi.org/10.1016/j.apergo.2020.103286.
Khan, A., et al., 2021. Integration of bim and immersive technologies for aec: A scientometric-swot analysis and critical content review. Buildings 11 (3), 1–34. https://doi.org/10.3390/buildings11030126.
Khan, N., et al., 2021. An adaptive game-based learning strategy for children road safety education and practice in virtual space. Sensors 21 (11), 1–21. https://doi.org/10.3390/s21113661.
Le, Q., et al., 2015. A framework for using mobile based virtual reality and augmented reality for experiential construction safety education. The International journal of engineering education 31 (3), 713–725.
Le, Q.T., Pedro, A., Park, C.S., 2015. A Social Virtual Reality Based Construction Safety Education System for Experiential Learning. Journal of Intelligent and Robotic Systems: Theory and Applications 79 (3–4), 487–506. https://doi.org/10.1007/s10846-014-0112-z.
Leder, J., et al., 2019. Comparing immersive virtual reality and powerpoint as methods for delivering safety training: Impacts on risk perception, learning, and decision making. Safety Science 111, 271–286. https://doi.org/10.1016/j.ssci.2018.07.021.
Li, N.F., Xiao, Z., 2018. A fire drill training system based on VR and kinect somatosensory technologies. International Journal of Online Engineering 14 (4), 163–176. https://doi.org/10.3991/ijoe.v14i04.8398.
Li, X., et al., 2018. A critical review of virtual and augmented reality (VR/AR) applications in construction safety. Automation in Construction 86, 150–162. https://doi.org/10.1016/j.autcon.2017.11.003.
Li, M., et al., 2020. A Virtual Reality Platform for Safety Training in Coal Mines with AI and Cloud Computing. Discrete Dynamics in Nature and Society 2020. https://doi.org/10.1155/2020/6243085.
Liang, Z., Zhou, K., Gao, K., 2019. Development of Virtual Reality Serious Game for Underground Rock-Related Hazards Safety Training. IEEE Access 7, 118639–118649. https://doi.org/10.1109/ACCESS.2019.2934990.
Liu, X., 2013. Full-Text Citation Analysis : A New Method to Enhance. Journal of the American Society for Information Science and Technology 64 (July), 1852–1863.
Lovreglio, R., et al., 2021. Comparing the effectiveness of fire extinguisher virtual reality and video training. Virtual Reality 25 (1), 133–145. https://doi.org/10.1007/s10055-020-00447-5.
Mariš, L., Fanfarova, A., 2017. Modern training process in safety and security engineering. Key Engineering Materials 755, 202–211. https://doi.org/10.4028/www.scientific.net/KEM.755.202.
Martínez-Aires, M.D., López-Alonso, M., Martínez-Rojas, M., 2018. Building information modeling and safety management: A systematic review. Safety Science 101, 11–18. https://doi.org/10.1016/j.ssci.2017.08.015.
Matsas, E., Vosniakos, G.C., 2017. Design of a virtual reality training system for human–robot collaboration in manufacturing tasks. International Journal on Interactive Design and Manufacturing 11 (2), 139–153. https://doi.org/10.1007/s12008-015-0259-2.
Milgram, P., 2011. A Taxonomy of Mixed Reality Visual Displays. Industrial Engineering 12, 1–14.
Mora-Serrano, J., Muñoz-La Rivera, F., Valero, I., 2021. Factors for the automation of the creation of virtual reality experiences to raise awareness of occupational hazards on construction sites. Electronics (Switzerland) 10 (11). https://doi.org/10.3390/electronics10111355.
Neguţ, A., et al., 2016. Task difficulty of virtual reality-based assessment tools compared to classical paper-and-pencil or computerized measures: A meta-analytic approach. Computers in Human Behavior 54, 414–424. https://doi.org/10.1016/j.chb.2015.08.029.
Nkomo, H., Niranjan, I., Reddy, P., 2018. Effectiveness of Health and Safety Training in Reducing Occupational Injuries Among Harvesting Forestry Contractors in KwaZulu-Natal. Workplace Health and Safety 66 (10), 499–507. https://doi.org/10.1177/2165079918774367.
Occupational Safety and Health Administration (2022) *Plan. Provide. Train. Three simple steps to preventing falls.* Available at: https://www.osha.gov/stop-falls#:~:text=FALLS ARE THE LEADING CAUSE,construction fatalities (BLS data).
Oraee, M., et al., 2017. Collaboration in BIM-based construction networks: A bibliometric-qualitative literature review. International Journal of Project Management 35 (7), 1288–1301. https://doi.org/10.1016/j.ijproman.2017.07.001.
Ouyang, S.G., et al., 2018. A Unity3D-based interactive three-dimensional virtual practice platform for chemical engineering. Computer Applications in Engineering Education 26 (1), 91–100. https://doi.org/10.1002/cae.21863.
O'connor, T., et al., 2014. Occupational safety and health education and training for underserved populations. New Solutions 24 (1), 83–106. https://doi.org/10.2190/NS.24.1.d.

Pantelidis, V.S., 2009. Reasons to Use Virtual Reality in Education and Training Courses and a Model to Determine When to Use Virtual Reality. Themes in Science and Technology Education 2, 59–70.
Pedram, S., et al., 2021. Cost–benefit analysis of virtual reality-based training for emergency rescue workers: a socio-technical systems approach. Virtual Reality 25 (4), 1071–1086. https://doi.org/10.1007/s10055-021-00514-5.
Poyade, M., et al., 2021. A Transferable Psychological Evaluation of Virtual Reality Applied to Safety Training in Chemical Manufacturing. Journal of Chemical Health and Safety 28 (1), 55–65. https://doi.org/10.1021/acs.chas.0c00105.
Qiao, Q., Yunusa-Kaltungo, A., Edwards, R.E., 2021. Towards developing a systematic knowledge trend for building energy consumption prediction. Journal of Building Engineering 35 (November). https://doi.org/10.1016/j.jobe.2020.101967.
Rahouti, A., et al., 2021. Prototyping and Validating a Non-immersive Virtual Reality Serious Game for Healthcare Fire Safety Training. Fire Technology 57 (6), 3041–3078. https://doi.org/10.1007/s10694-021-01098-x.
Rauh, S.F., et al., 2021. MR On-SeT: A Mixed Reality Occupational Health and Safety Training for World-Wide Distribution. International Journal of Emerging Technologies in Learning 16 (5), 163–185. https://doi.org/10.3991/ijet.v16i05.19661.
Renganayagalu, S. kumar, Mallam, S.C. and Nazir, S. (2021) Effectiveness of VR Head Mounted Displays in Professional Training: A Systematic Review, Technology, Knowledge and Learning. Springer Netherlands. 10.1007/s10758-020-09489-9.
Rey-Becerra, E., et al., 2021. The effectiveness of virtual safety training in work at heights: A literature review. Applied Ergonomics 94 (March). https://doi.org/10.1016/j.apergo.2021.103419.
Robertson, G. *et al.* (1993) Three views of virtual reality: Nonimmersive virtual reality, 26(2), pp. 81–83.
Rodríguez-Abad, C., et al., 2021. A systematic review of augmented reality in health sciences: A guide to decision-making in higher education. International Journal of Environmental Research and Public Health 18 (8). https://doi.org/10.3390/ijerph18084262.
Rubio-Romero, J.C., Rubio, M.C., García-Hernández, C., 2013. Analysis of Construction Equipment Safety in Temporary Work at Height. Journal of Construction Engineering and Management 139 (1), 9–14. https://doi.org/10.1061/(asce)co.1943-7862.0000567.
Saghafian, M., et al., March 2021. (2020) The Evaluation of Virtual Reality Fire Extinguisher Training. Frontiers in Psychology 11. https://doi.org/10.3389/fpsyg.2020.593466.
Sanmiquel, L., et al., 2018. Analysis of occupational accidents in underground and surface mining in Spain using data-mining techniques. International Journal of Environmental Research and Public Health 15 (3), 1–11. https://doi.org/10.3390/ijerph15030462.
Shang, K.C., Lu, C.S., 2009. Effects of safety climate on perceptions of safety performance in container terminal operations. Transport Reviews 29 (1), 1–19. https://doi.org/10.1080/01441640802264943.
Shiradkar, S., et al., 2021. Virtual world as an interactive safety training platform. Information (Switzerland) 12 (6), 1–19. https://doi.org/10.3390/info12060219.
Snyder, H., 2019. Literature review as a research methodology: An overview and guidelines. Journal of Business Research 104, 333–339. https://doi.org/10.1016/j.jbusres.2019.07.039.
U. S. Department of Labors, 2021. National Census of Fatal Occupational Injuries Summary, Bureau of Labour. Statistics December(USDL-21-2145), 11.
Udeozor, C., et al., 2021. Perceptions of the use of virtual reality games for chemical engineering education and professional training. Higher Education Pedagogies 6 (1), 175–194. https://doi.org/10.1080/23752696.2021.1951615.
van Eck, N.J. and Waltman, L. (2014) 'Visualising bibliometric networks', in Y. Ding, R. Rousseau, and D. Wolfram (eds) *Measuring Scholarly Impact*. Springer, pp. 285–320. 10.1007/978-3-319-62543-0_4.
Vukšić, V.B., Ivančić, L., Vugec, D.S., 2018. A Preliminary Literature Review of Digital Transformation Case Studies. International Journal of Computer and Information Engineering 12 (9), 737–742. https://doi.org/10.5281/zenodo.1474581.
Wu, H.K., et al., 2013. Current status, opportunities and challenges of augmented reality in education. Computers and Education 62, 41–49. https://doi.org/10.1016/j.compedu.2012.10.024.
Wuni, I.Y., Shen, G.Q.P., Osei-Kyei, R., 2019. Scientometric review of global research trends on green buildings in construction journals from 1992 to 2018. Energy and Buildings 190, 69–85. https://doi.org/10.1016/j.enbuild.2019.02.010.
Xu, Z., Zheng, N., 2021. Incorporating virtual reality technology in safety training solution for construction site of urban cities. Sustainability (Switzerland) 13 (1), 1–19. https://doi.org/10.3390/su13010243.
Xu, J., et al., 2018. A VR-based the emergency rescue training system of railway accident. Entertainment Computing 27 (March), 23–31. https://doi.org/10.1016/j.entcom.2018.03.002.
Xu, L.Da, Xu, E.L., Li, L., 2018. Industry 4.0: State of the art and future trends. International Journal of Production Research 56 (8), 2941–2962. https://doi.org/10.1080/00207543.2018.1444806.
Yuan, D., Jin, X. and Zhang, X. (2012) Building a immersive environment for firefighting tactical training, in *Proceedings of 2012 9th IEEE International Conference on Networking, Sensing and Control, ICNSC 2012*. IEEE, pp. 307–309. 10.1109/ICNSC.2012.6204935.
Zhao, D., Lucas, J., 2015. Virtual reality simulation for construction safety promotion. International Journal of Injury Control and Safety Promotion 22 (1), 57–67. https://doi.org/10.1080/17457300.2013.861853.
Zhao, D., et al., 2016. Integrating safety culture into OSH risk mitigation: a pilot study on the electrical safety. Journal of Civil Engineering and Management 22 (6), 800–807. https://doi.org/10.3846/13923730.2014.914099.
Zhong, D., et al., 2021. Effects of virtual reality cognitive training in individuals with mild cognitive impairment: A systematic review and meta-analysis. International Journal of Geriatric Psychiatry 36 (12), 1829–1847. https://doi.org/10.1002/gps.5603.