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A systematic review of the application of immersive technologies for safety and health management in the construction sector

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ABSTRACT

Introduction: The construction industry employs about 7% of global manpower and contributes about 6% to the global economy. However, statistics have depicted that the construction industry contributes significantly to workplace fatalities and injuries despite multiple interventions (including technological applications) implemented by governments and construction companies. Recently, immersive technologies as part of a suite of industry 4.0 technologies, have also strongly emerged as a viable pathway to help address poor construction occupational safety and health (OSH) performance. *Method:* With the aim of gaining a broad view of different construction OSH issues addressed using immersive technologies, a review on the application of immersive technologies for construction OSH management is conducted using the preferred reporting items for systematic reviews and meta-analysis (PRISMA) approach and bibliometric analysis of literature. This resulted in the evaluation of 117 relevant papers collected from three online databases (Scopus, Web of Science, and Engineering Village). *Results*: The review revealed that literature have focused on the application of various immersive technologies for hazard identification and visualization, safety training, design for safety, risk perception, and assessment in various construction works. The review identified several limitations regarding the use of immersive technologies, which include the low level of adoption of the developed immersive technologies for OSH management by the construction industry, very limited research on the application of immersive technologies for health hazards, and limited focus on the comparison of the effectiveness of various immersive technologies for construction OSH management. *Conclusions and Practical Applications:* For future research, it is recommended to identify possible reasons for the low transition level from research to industry practice and proffer solutions to the identified issues. Another recommendation is the study of the effectiveness of the use of immersive technologies for addressing health hazards in comparison to the conventional methods.

1. Introduction

The advancement of high-power computers and information technology has significantly enhanced the digitalization of fundamental processes within various industries, so as to boost reliability and reduce direct exposures of humans to harmful operations. One of the most prominent conveyors of such digital revolutions is industry 4.0. Industry 4.0 (also referred to as fourth industrial revolution) is the fourth industrialization process of the manufacturing sector, which involves the application of emerging technologies in the establishment and management of essential business processes (Cugno et al., 2021). The emerging technologies used in the revolution of the industrial sectors include robotics, big data and analytics, immersive technologies, additive manufacturing, autonomous operations, cloud computing, cyber-security and internet of things (Rüßmann et al., 2015). Industry 4.0 was pioneered in 2011 at the Hannover Fair event in Germany, which brought about the present-day generation of industrial revolution (Tay et al., 2018). Industry 4.0 is increasingly becoming highly appreciated by both practitioners and researchers within various industries, including the construction industry. It has been observed from literature that researchers in the construction industry have developed interests in the application of immersive technologies (ImTs), which is among the industry 4.0 technologies, in the management of construction activities. ImTs are technologies that are used for the simulation of the real-world environment and activities to deliver a sense of immersion in the simulated environment (Abbas et al., 2019; Khan et al., 2021). For example, a study conducted on the use of ImTs for facility management in

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the construction industry resulted into faster and easier access to information on the facility management phase when compared to the 2D blueprint-based facility management work (Chung et al., 2021). A study explored the innovative use of ImTs in tackling the shortage of young manpower in the electrical construction industry (Wen & Gheisari, 2021). The approach of storytelling using ImTs was adopted to narrate the success stories of the electrical trade in the construction industry to young students with the aim of inducing interest in the electrical construction industry to the students (Wen & Gheisari, 2021). Despite the advancement of industry 4.0 technologies in other sectors such as manufacturing industry (Zeba et al., 2021) and aviation industry (Vahdatikhaki et al., 2019), the uptake within the construction industry has been relatively low.

Studies have revealed that the construction industry is a very large industry, consisting of about 7% of global manpower and contributing about 6% of the world's gross domestic product (GDP) (Adami et al., 2021; Bhagwat et al., 2021). Despite its huge impact on employment and the global economy, the construction industry is inherently dangerous, thereby making it one of the most hazardous industries (Comu et al., 2021). The International Labour Organisation (ILO) evaluated the global annual record of fatal injuries in the construction industry to be over 100,000 (ILO, 2015). The construction industry has one of the highest records of occupational accidents and diseases, approximately 3.5 times the average rate of fatal injuries to workers than in all other industries (Health and Safety Executive, 2015) Also, the average rate of nonfatal injuries in the construction industry is approximately 1.5 times the average rate of nonfatal injuries in all industries (Health and Safety Executive, 2015). These unpleasant statistics clearly depict that the number and percentage of fatalities and injuries in the construction industry are immensely high and, therefore, require urgent intervention.

According to Park and Kim (2013), various studies have stated that the establishment and operation of consistent, appropriate, and well-planned safety management process, inspection, and training would have averted many of the accidents in the construction industry. The construction industry has, however, been very slow in incorporating digital tools for its safety management, despite the utilization of digital tools for its workflows (Afzal et al., 2021). Afzal et al. (2021) maintain that the conventional methods used for safety management in construction have their inadequacies in reducing the risks of accidents and fatalities and, therefore, recommends the use of technology-driven applications such as ImTs for construction safety management. Zhao et al. (2016) stated that the construction industry has a high turnover of employees as construction activities are highly work-intensive, which makes the management of occupational safety and health (OSH) more difficult than other industries. It has, therefore, become imperative to adopt an alternative method to the contemporary method used in tackling the OSH issues in the construction industry.

This study focuses on the application of ImTs as part of the emerging industry 4.0 technologies in addressing the OSH challenges in the construction industry. Academic researchers and industry practitioners may not have in-depth knowledge of the limitations and gaps in the application of ImTs for addressing OSH challenges in construction due to the overwhelmingly diverse and vast nature of studies in this area (Li et al., 2018). Li et al. (2018) discovered that ImTs have been explored and temporarily applied in various areas of OSH management such as training and education, hazard identification, risk perception of construction workers, and many more. It is noticed that virtual reality (VR), augmented reality (AR), and mixed reality (MR) are the trending realities in ImTs (Pavithra et al., 2020). VR, AR, and MR are the prominent ImTs in the construction industry (Alizadehsalehi et al., 2020; Khan et al., 2021). ImTs present an opportunity to reduce the rates of accidents on construction sites (Ahmed, 2019) thereby making them the cornerstone of study, as it is envisaged that a better understanding of their proficiency could significantly ease the adoption of ImTs for construction OSH management. However, at present, there is lacking within the literature a comprehensive understanding of the breadth of the role/potentials of ImTs in addressing OSH challenges in construction due to the diverse and vast nature of studies in this area (Li et al., 2018). Some reviews have been conducted on the application of ImTs (especially VR and AR for construction OSH management), but most of these reviews are often individualized owing to their focus on the application of just one or two ImTs on different OSH areas/topic in construction (Li et al., 2018). Other reviews have focused on the use of ImTs on a particular OSH area/topic in construction, such as for safety training (Gao et al., 2019). However, there is an underrepresentation of reviews that show the application of ImTs in various OSH areas, and various types of OSH hazards and conditions in construction.

The aim of this study is, therefore, to systematically review literature in order to: (1) investigate the current state of application of ImTs in construction OSH management; (2) investigate the challenges involved in the integration of ImTs in construction OSH management; and (3) propose recommendations regarding the application of ImTs in the management of OSH in construction OSH management.

The research questions that therefore directed this study are:

1. What is the current state of research on the application of ImTs for construction OSH management? In particular, what types of construction OSH areas, hazards, and conditions are addressed by ImTs in the academic literature?
2. What are the challenges/limitations and future research directions regarding the application of ImTs for construction OSH management?

The paper commences with an overview of the definitions and concepts 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 construction OSH management are presented, which highlights the OSH issues/areas and the types of OSH hazards and conditions addressed by ImTs in the construction industry. This is then followed by the challenges involved in applying ImTs for construction OSH management as seen in literature and consequently the recommendations for future works pertaining to research on the applications of ImTs for construction OSH management and finally, the conclusions.

2. Concepts and tools of immersive technologies

VR, AR and MR are the major types of ImTs that come under the umbrella term 'extended reality' and this can be regarded as a complete spectrum ranging from reality to virtuality (Khan et al., 2021). VR is a technology that is used for the development of computerized environment in which users feel isolated from the real world through the total immersion of the users in the computerized environment with the use of electronic devices such as head mounted displays (HMD), glasses, or the setup of multi-display screens (Davila Delgado et al., 2020). Users of VR technology can experience the sense of presence in a virtual environment with the use of a head-mounted VR device or the setup of two or three large projected screens referred to as cave automatic virtual environment (CAVE) (Shafiq & Afzal, 2020). VR has been used to expose learners to a particular work environment such as working at height experiences with realistic perception (Chander et al., 2021).

AR, another type of ImT, is the superimposition of digital information and images on the real-world environment to enhance the contextual perception of the environment of the users (Davila Delgado et al., 2020). AR is the amalgamation of the real-world scenario and computerized images and videos to produce a blended but improved view of the world (Ahmed, 2019). In contrast with VR, which absolutely comprises of a computerized model, AR blends the real and virtual worlds (Hallowell et al., 2016).

MR is the environment where real-world and digital objects coexist and interact in real-time (Hasanzadeh et al., 2020b). While AR involves the overlaying of virtual objects on real-world objects, MR involves the interactions between users and virtual objects in a real-world environment (Gao et al., 2019). Although ImTs are not new forms of technology, the industrial application of this technology is at its nascent stage as there has only been a routine and massive scale of use by the industry and the general public within the last five years (Mora-Serrano et al., 2021).

Based on the existing literature, the virtual environment can be created using computer software such as Unity game engine (Li et al., 2012b; Joshi et al., 2021; Mora-Serrano et al., 2021), Torque game engine (Zhao & Lucas, 2015; Zhao et al., 2016), Unreal game engine (Albert et al., 2014; Kim et al., 2021), and many more as shown in Table 1. There are various kinds of computer software that are developed for the modeling of virtual objects to be used in virtual environments, which will then be exported to game engines to be programmed using the required programming language. As depicted in Table 1, different game engines make use of different programming languages to program the various virtual objects in a virtual environment. The primary language of Unity game engine is C# (Joshi et al., 2021; Mora-Serrano et al., 2021), while the programming of modeled objects in Unreal game (Albert et al., 2014) and Torque 3D game engines is based on C++ (Zhao & Lucas, 2015).

An example of a computer software that is used for the modeling of virtual objects as seen in literature is Autodesk 3ds max (Sacks et al., 2013; Zhao & Lucas, 2015; Pooladvand et al., 2021). Albert et al. (2014) and Kim et al. (2021) used computer modeling software (i.e., Autodesk 3ds Max and Autodesk Maya) to draw out the virtual components to be used in the virtual environment developed using a computer game engine (i.e., unreal engine). Bhagwat et al. (2021) also used computer modeling software (i.e. Autodesk Revit and Trimble Sketchup) tools to create and model the virtual objects to be used in the virtual environment created by a computer game engine (i.e., Unity game engine). Furthermore, a computer modeling software (i.e., Blender) was used in a study to model a virtual environment consisting of a building under construction, its background (including the addition of colors and realistic textures to building components), as well as the construction workers for virtual animation and game scenarios (Pedro et al., 2016). Côté and Beaulieu (2019) developed a photorealistic environment by taking pictures of a road construction site and exported these pictures into a three dimensional (3D) reality modeling software (i.e., Bentley Context Capture) for assembly into photorealistic 3D mesh, prior to exporting into computer game engines.

Another example of a software tool used for the development of a virtual environment as observed in literature is the Photon Unity Networking (PUN). PUN cloud server was used for the implementation of a multi-user VR system by allowing multiple users to interact with each other in the same virtual environment (Shi et al., 2019). Users can see the movements of the avatars of other users in the virtual environment as the users regularly transmit their moving positions and body rotations to the other users in the same virtual environment (Shi et al., 2019). In a multi-user virtual environment, different users are connected via a multi-user platform, which includes a database that stores the true values for all pre-defined inputs of the users, including a knowledge and rule module for validation of the inputs of the users (Li et al., 2012a). The multi-user VR system, when turned on automatically, searches and connects to the server while an alternative method for connection to the server is for users to provide a suitable internet protocol (IP) address for manual connection (Li et al., 2012a).

While the roles of the aforementioned software tools in pioneering the creation of a typical VR environment are uncontested, there are also various hardware kits that are often utilized to mimic a sense of presence for human beings within such environments. To achieve representative sense of awareness, stimulating real-life senses such as sight, hearing, touch, smell, and taste are very essential (Suh & Prophet, 2018; Khan et al., 2021). These hardware kits provide the feeling of presence through vision, and they are generally known as VR headsets. VR headsets are stereoscopic head-mounted display units that use binocular vision to produce imaginary visions of depth (Habibnezhad et al., 2021). Examples of VR headsets as seen in literature include HTC Vive pro headset (Habibnezhad et al., 2021), Oculus head-mounted display unit (Xu & Zheng, 2021) and 3D stereo glasses (Sacks et al., 2015). These kits create sense of presence through vision as human beings need to wear them in order to immerse themselves into a virtual environment.

To further enhance sense of presence within typical virtual environments, the incorporation of sounds through simple stereo sounds or as spatial sounds was advocated in an earlier study by Meghanathan et al. (2021). Sounds of activities in the virtual environment can be included to enhance the feeling of presence, including the sound of footsteps or the engines of earth-moving equipment such as loaders. For example, a study conducted by Sacks et al. (2013) used a stereo sound system to enhance the sense of presence in the virtual environment by adding audio tracks of vehicles traveling, as well as some background sounds of typical construction sites, while Lu and Davis (2016) used computer and headphones to replicate similar sounds in their virtual environment. According to Lu and Davis (2016), the sounds common to most construction sites include those from the sound of vehicles (trucks), heavy equipment (tower cranes, excavators, loaders, drillers, mixers, etc.), physical interactions (talking, walking, etc.), and manual construction activities (creaking of woods, knocking of hammers, etc.). A further attempt to enhance the representativeness of real-life scenarios within virtual environments entailed incorporating the sense of feeling when users interact with virtual environments, which have been achieved via various enabling

Table 1
Examples of different game engines and their specifications.

	Game Engine				
	Unity	**Unreal**	**Torque**	**CryEngine**	**Microsoft XNA Game Studio**
Developer	Unity Technologies	Epic Games	GarageGames	Crytek	Microsoft
Operating System	Windows, Mac, Linux	Windows, Mac, Linux	Windows, Mac, Linux	Windows, Linux	Windows
Programming Language	C#	C++	C++	C++, C#, Lua	C#, Visual Basic.NET
Primary Usage	Game development	Game development	Game development	Game development	Game development

technologies. For example, a hardware controller (Nintendo Wii controllers) was used in a study conducted by You et al. (2018) to aid the users of a virtual masonry in grabbing, holding, and releasing concrete blocks while attempting to build a wall in the virtual masonry created using Unity 3D game engine. In a related study, a hardware controller (HTC Vive controller), was used by Adami et al. (2021) to enable the research participants to interact with virtual workers and objects in a VR-based training. Furthermore, Adami et al. (2021) used a treadmill (Virtuix Omni VR treadmill) to implement the navigation of demolition robots and teleoperate in different locations.

Finally, as observed from literature, examples of technological hardware tools used for the collection of data from participants of studies on the use of ImTs include Emotiv EPOC + EEG sensors, Omron electronic sphygmomanometer and, Tobii Pro X2-30 Hz eye tracker device. These technologies were used to collect electroencephalography (EEG) data (Emotiv EPOC + EEG sensors) of participants of a VR-based construction safety training, and to collect data on the blood pressure and heart rates (Omron electronic sphygmomanometer) of these participants in order to assess the physical and mental state of health of the trainees in a study conducted with a view of developing a VR-based system to curb the chronic health conditions suffered by construction workers due to overtime work (Huang et al., 2021). In addition, an eye tracker (Tobii Pro X2-30 Hz eye tracker device) was used in tracking the eye movements of participants of a study on virtual construction safety training to measure the concentration and adaptation levels of the participants (Comu et al., 2021).

3. Methodology

It has been observed that there is an underrepresentation of reviews that render a holistic view of the application of ImTs in various OSH areas, and various types of OSH hazards and conditions in construction. The lack of comprehensive academic documents makes it challenging for researchers to adequately examine the proficiency of all approaches under all scenarios at a glance. Additionally, the current study adopts the PRISMA-based systematic literature review (SLR) approach, which implies that there is a very logical approach to the definition of keywords, database selection, articles inclusion/exclusion, and research timeline, which makes it very easy for future researchers to determine the exact contributions as well as limitations of the study. The review was conducted based on the guidance from Page et al. (2021) on PRISMA methodology.

3.1. Review approach

The methodology adopted in this study was a SLR using PRISMA. A SLR can be defined as a review of literature that involves cogent collation of all evidences relevant to a particular field of study, with the aim of obtaining answers to a specific research question (Moher et al., 2016). There were four reviewers who screened each retrieved paper and these reviewers worked independently. In addition, a reference management system (Mendeley) was used to collate the response from each reviewer in real-time. The literature search was conducted using three online databases: 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 industrial safety, technology, and construction. The keywords used for the search were divided into three fields: the first field focusing on the technology, the second field on the construction industry, and the third field on OSH as shown in Fig. 1.

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

(TITLE-ABS-KEY ("Industry 4.0" OR "Construction 4.0" OR "Augmented Reality" OR "AR" OR "Virtual Reality" OR "Mixed Reality" OR "MR") AND TITLE-ABS-KEY ("Construction" OR "Construction Industry") 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 search strings applied to verify the title, abstract, and keywords of the papers collected from Web of Science (WoS) database is:

((TI=(("Industry 4.0" OR "Construction 4.0" OR "Augmented Reality" OR "AR" OR "Virtual Reality" OR "VR" OR "Mixed Reality" OR "MR") AND ("Construction" OR "Construction Industry") AND ("Occupational Health and Safety" OR "Occupational Safety and Health" OR "Safety and Health" OR "Health and Safety" OR "Safety" OR "Health"))) OR (AB=(("Industry 4.0" OR "Construction 4.0" OR "Augmented Reality" OR "AR" OR "Virtual Reality" OR "VR" OR "Mixed Reality" OR "MR") AND ("Construction" OR "Construction Industry") AND ("Occupational Health and Safety" OR "Occupational Safety and Health" OR "Safety and Health" OR "Health and Safety" OR "Safety" OR "Health")))) OR (AK=(("Industry 4.0" OR "Construction 4.0" OR "Augmented Reality" OR "AR" OR "Virtual Reality" OR "VR" OR "Mixed Reality" OR "MR") AND ("Construction" OR "Construction Industry") 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 search strings applied to verify the title, abstract, and keywords of the papers collected from Engineering Village (EV) database is:

(((("Industry 4.0" OR "Construction 4.0" OR "Augmented Reality" OR "AR" OR "Virtual Reality" OR "VR" OR "Mixed Reality" OR "MR") WN KY) AND (("Construction" OR "Construction Industry")

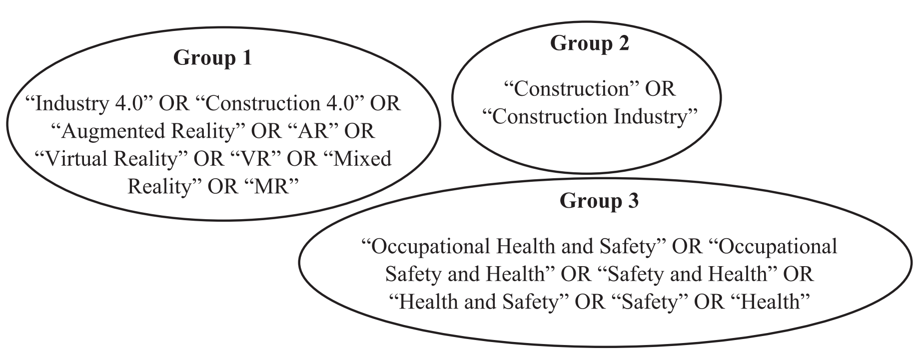

Fig. 1. Keywords for systematic literature review.

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 967 publications from Scopus, 343 publications from WoS, and 1,040 publications from EV databases, making a total of 2,350 publications. The search strings were then limited to journal articles and reviews written in English language only. This is because journal articles and reviews are peer-reviewed and provide a more extensive and higher quality information when compared to other paper types such as conference papers and editorials (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 have very minimal impact on the results (Butler & Visser, 2006; Hosseini et al., 2018; Wuni et al., 2019). The total number of relevant publications after filtering the search string based on predefined inclusion and exclusion criteria was 953 publications, with 384, 204, and 365 articles from Scopus, WoS, and EV databases, respectively. These publications were then screened by their titles and abstracts as regards to the relevance of these publications to the scope of this study. The title and abstract screening of the publications filtered out 711 publica-

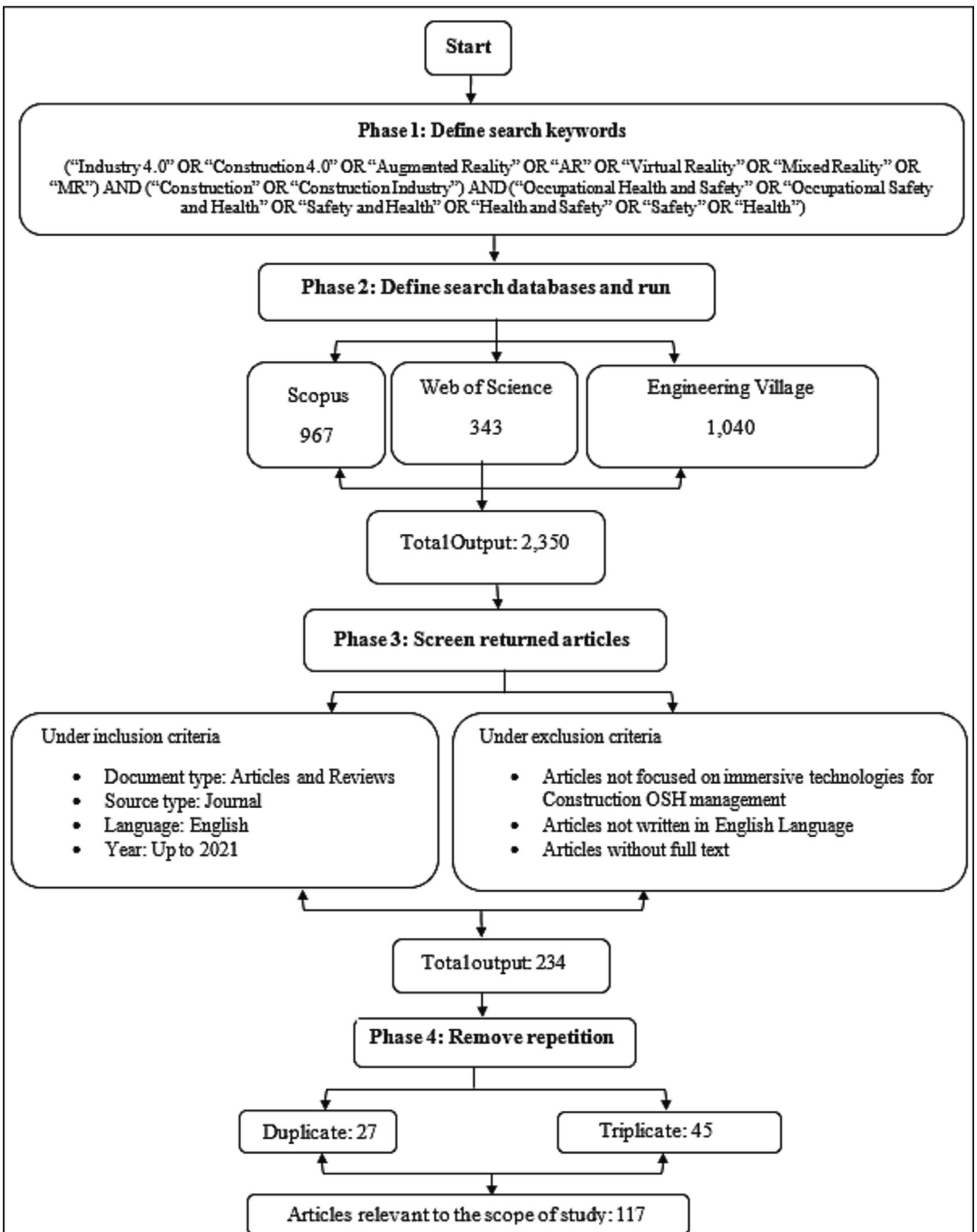

Fig. 2. PRISMA-based SLR flow diagram.

tions. For example, a publication by Chen et al. (2019) on the "*exploration on the difference in the taxonomic diversity and ecological exergy of the microbenthic faunal community before and after artificial reefs (AR) construction in artificial reefs habitat in the Pearl River Estuary, China*" was one of many rejected publications due to the lack of relevance of their contents.

Eventually, 245 publications were considered relevant across all databases, with a distribution of 79, 83, and 83 publications from Scopus, WoS and EV databases, respectively. The next stage of the filtration involved using a reference management system (in this case, Mendeley) to remove duplicate articles, which revealed 11 duplicates from EV database alone, because it comprises of 4 smaller but distinct database (namely, Compendex, Inspec, Geobase, and Georef). The exclusion of these 11 repeated articles further reduced the outputs from EV to 72 relevant publications and 234 publications in total. Furthermore, 45 triplicates from the three databases (14 duplicates from Scopus and WoS databases; 8 duplicates from Scopus and EV and 5 duplicates from WoS and EV) were identified and excluded accordingly. In order 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. Once all duplicates and triplicates were removed, a total of 117 relevant papers were then 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 managing OSH in the construction industry, with notable areas including hazard identification and visualization, training and education, risk perception assessment, and design for safety by using approaches such as literature review (Frank Moore & Gheisari, 2019), pilot study (Eiris et al., 2020), randomized controlled trial (Nykänen et al., 2020), case study (Guo et al., 2012), survey (Adami et al., 2021) and simulations (Lucena & Saffaro, 2020). However, the population and coverage of such studies are very limited as well as disproportionate to the poor OSH performance record within the construction industry. Additionally, there is a glaring underrepresentation of reviews that provide a holistic view of research activities related to the application of ImTs for the management of different facets of OSH with ImTs. The uniqueness of this study is further buttressed because none of the few

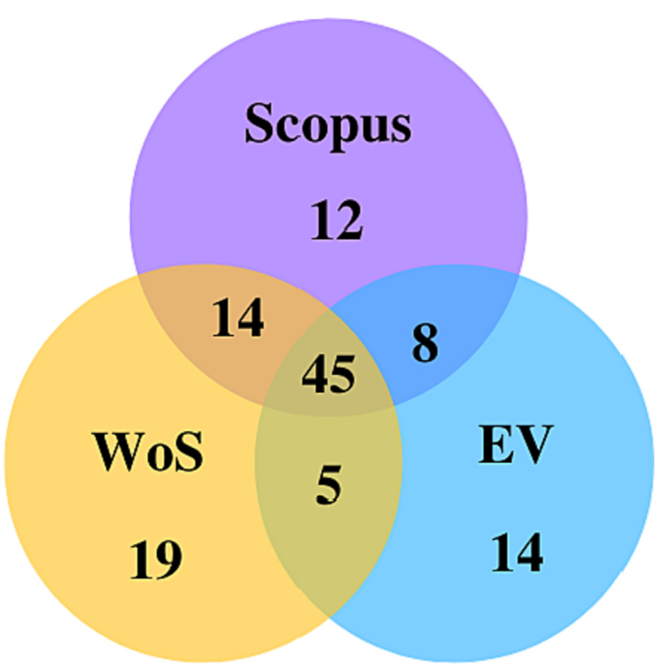

Fig. 3. Venn diagram of the distribution articles across databases.

existing reviews are systematic in nature, which makes it more challenging to verify robustness, especially with regards to the justifications for the included articles, search keywords, and timelines covered, which are vital for planning future research endeavors. Data extraction forms with the use of Microsoft Excel were used to obtain data from the research team. Details such as the year and location of study, aims of the study, OSH areas, hazards and conditions addressed by ImTs, the challenges associated with the use of ImTs for OSH management, and recommended future directions pertaining to applications of ImTs for construction OSH management were extracted using the data extraction form. One of the limitations of the review process is the focus of the information sources, which was limited to only Scopus, WoS, and EV. Another limitation is that only journal articles were reviewed.

3.1.1. Analysis

The initial stage of the analysis entailed observing the bibliometric data. To achieve this, the frequency of the included articles was analyzed based on year of publication, title of journal, location of study, and research method. The frequency analysis was facilitated using an analytic framework to enable the annotation of the included articles and extraction of relevant information pertaining to 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 construction OSH management, the different areas of construction OSH addressed by the applications of ImTs, the types of construction OSH hazards and conditions addressed by ImTs, the construction life cycle stage(s) addressed, and the hierarchy of control implemented. The SLR further identified future research areas pertaining to the applications of ImTs for construction OSH management.

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 with regards to SLR is that it makes the identification of peaks and troughs in data easy. It also enables researchers to match notable events and to aid research planning. The analytical framework adopted by this study is as shown in Table 2.

4.1. Bibliometric analysis

Bibliometric analysis is the mathematical analysis of literature and their properties, which include authorships, document type, and timeline and visualizes the physical aspect of the scientific research with the use of mapping tools (Akinlolu et al., 2020). A bibliometric analysis of articles is a very useful method of analysis as it shows the interactions amongst included articles, which makes it easier to understand how researchers have been able to establish an even distribution between quality, quantity, and the impact of such studies (Qiao et al., 2021). In addition, bibliometric analysis contributes to effective research planning and interdisciplinary collaborations. The bibliometric analysis of the included articles in this study was conducted using VOSviewer, as VOS-

Table 2
Analytical Framework.

Location (Country) of study
Aims/objectives of study
Main findings/outcomes
Complementary/linked industry 4.0 technology
Limitations/challenges related to application of ImTs
OSH management Issue/Area/Aspect addressed by ImTs
Type of OSH hazard addressed by ImTs
Type of OSH condition addressed by ImTs
Life cycle stage
Hierarchy of control
Limitations of the study

viewer is a known software for bibliometric analysis of data obtained from prominent literature databases such as WoS and EV (Qiao et al., 2021).

4.1.1. Mapping of the Co-occurrence of keywords

A network of keywords provides a coherent illustration of a specified sphere of knowledge, provides in-depth understanding of topics covered, and the cognitive inter-relationships between these topics (Darko et al., 2019). Thus, the mapping of the co-occurrence of keywords was generated using VOSviewer software. From the visualization generated by VOSviewer, the labels and circles display items in the visualisation network while the distance between each item denotes the strength of their relationships (Akinlolu et al., 2020). Hence, the larger the distance between any two given points within the network, the weaker the relationship between the corresponding items and vice versa. Typically, the link strength between two keywords is directly proportional to the thickness of their linkage lines and is estimated via the number of publications in which such keywords jointly appear (Darko et al., 2019).

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). To, however, accomplish the co-occurrence network of keywords, best practices as suggested by Chen and Song (2017), Oraee et al. (2017), Jin et al. (2018), and Hosseini et al. (2018) were used in this study. Consequently, a total of 2,100 keywords were extracted using the fractional counting method. With a minimum number of 5 co-occurrence of keywords, 73 keywords co-occurred, and 7 significant clusters were identified. Fig. 4 shows a network visualization map of the 7 co-occurring keyword clusters with 773 links and a total link strength of 339. The size of the circles representing a keyword depicts the number of times it appeared as an author keyword in the articles obtained in this study. As seen in Fig. 4, this therefore means that the keywords that have distinctly larger nodes than the rest of the keywords include *virtual reality, augmented reality, safety, construction safety, and construction*. Each cluster of keywords and grouped by keywords and each cluster indicates keywords that co-occur

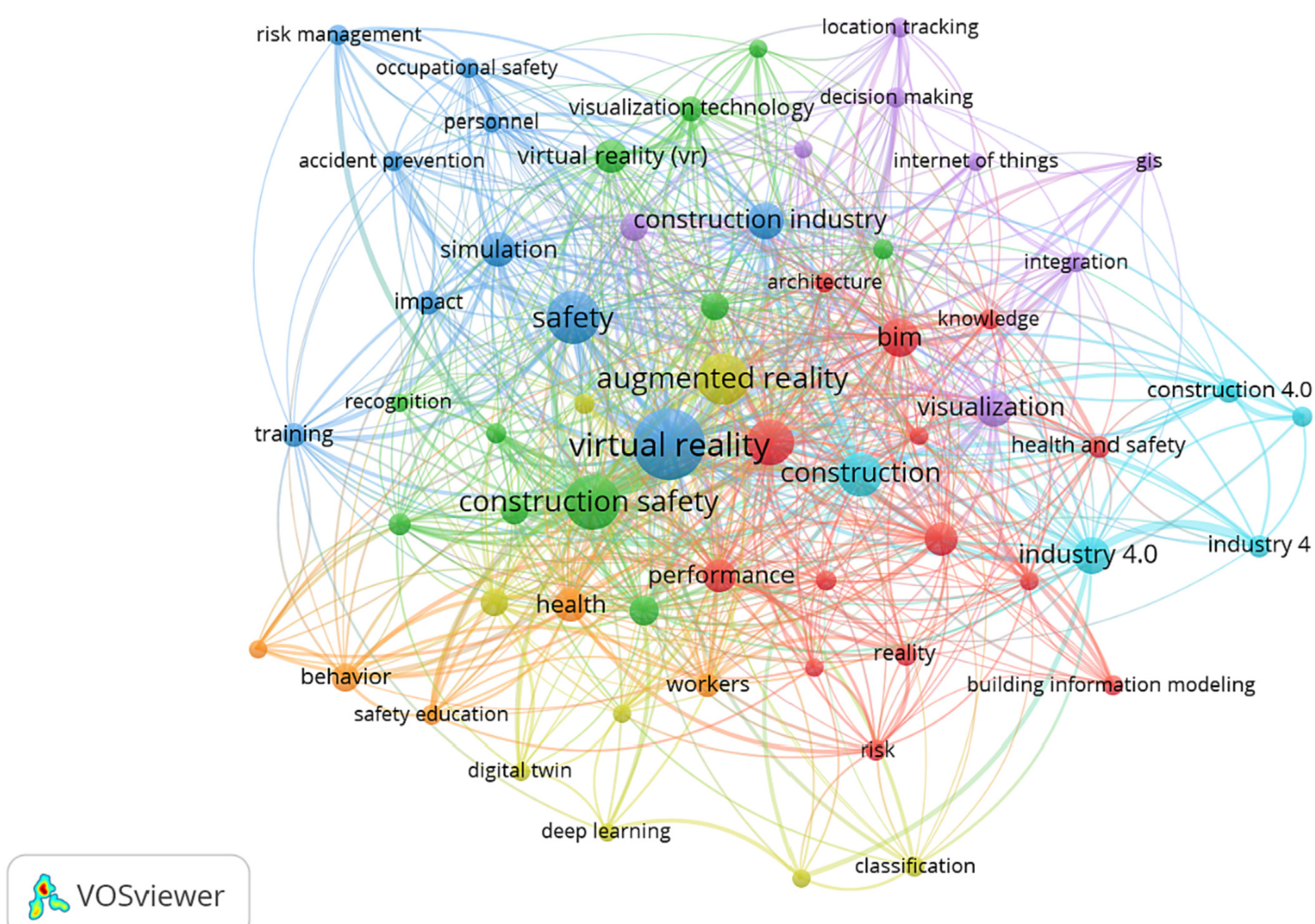

Fig. 4. Network of Co-occurrence of Keywords.

most frequently. This therefore means that keywords such as *safety, risk management, personnel, accident prevention and safety,* represented by the blue color, co-occurred frequently.

4.1.2. Mapping of co-authorship

Knowledge exchange, innovations and joint funding applications can be facilitated by the collaboration of researchers and institutions (Wuni et al., 2019). It is therefore necessary to visualize the network analysis of all the authors of articles, which assists in the identification of key collaboration in the research on ImTs for construction OSH management, which is presented in this section. Similarly, VOSviewer was used to conduct a network visualization of co-authorship, and the outcome is displayed in Fig. 5. This visualization included the mappings of the lead authors and their collaborators. This mapping was conducted to create a network of authors that had undertaken collaborative research on the applications of ImTs for construction OSH management. The type of analysis was set to "*co-authorship*" and the unit of analysis was set to "*authors*" in VOSviewer software, while the counting method selected was "*fractional counting.*" The minimum number of documents per author was set to 2 to filter authors that met the threshold. This generated 1,473 authors, including the lead and co-authors, with 134 meeting the set thresholds. The largest set of connected items was 35 items, as shown in Fig. 5. These connected items yielded 7 clusters, 63 links and a total link strength of 31. The overlay visualization co-authorship network shown in Fig. 5 shows that researchers such as Wang, I., Fang, X., Li, Z., and Yang, J. tend to collaborate more frequently.

4.1.3. Mapping of collaborations by country

In accordance with the aforementioned descriptions of keywords and authors network analyses, the collaboration network of countries within relevant study areas helps to recognize countries that are research-active (Darko et al., 2019). Hence, VOSviewer was again used to recognize the countries that are most influential in generating studies that focus on the applications of ImTs for construction OSH management. Similarly, the type of analysis selected was "*co-authorship*" with the unit of analysis set as "*countries*" and the counting method was "*fractional counting.*" In addition, the minimum number of documents of a country was set to 5 while the minimum number of citations of a country had a default setting of 0. The number of countries detected by VOSviewer software was 64 with 22 meeting the thresholds. The largest set of connected items was, however, 21 items as shown in Fig. 6, which shows the research-active countries in ImTs for construction OSH management. These connected items yielded 6 clusters, 60 links, and a total link strength of 82. As seen in Fig. 6, bigger nodes represent the United Kingdom, United States of America, China, and South Korea. It can also be seen from Fig. 6 that researchers and institutions from geographically close countries have a higher tendency to collaborate and cite the work of each other, such as: researchers from China, South Korea, Japan, and Taiwan in the Asian environment represented by the green cluster; Germany, Spain, UK, Norway, Portugal, and Italy from Europe represented by the red cluster; and the United States and Canada from North America represented by the blue cluster.

4.1.4. Distribution of publications per year

Fig. 7 shows the number of publications for every year a paper related to the scope of study of this review was published. The chart in Fig. 7 shows that there was little to no research on the application of ImTs for construction OSH management from 2000 and 2011 with no research conducted between 2002 and 2005 and between 2006 and 2010. Before 2012, the number of relevant papers published was not more than two papers, as shown in Fig. 7. There was a significant increase in the number of relevant papers published in 2012 with five more published papers than in 2011, with equal number of published papers in 2013. The significant increase in the number of papers in 2012 could be due to the launch of Industry 4.0 concept in 2011 (Yang & Gu, 2021). There was, however, a drop in the number of papers in 2014 from 2012 with two relevant papers published in 2014, with a significant increase again in 2015 and 2016 as seven relevant papers were published in both years. A final decline in the number of relevant published papers occurred in 2017 with five relevant papers published in 2017, which was less than the seven papers published in 2016. The decline in the number of papers could be due to the high proportion of publications on industry 4.0 focusing on engineering, communication, and business process management during this period (Petrillo et al., 2018). The distribution, however, showed an increasing trend of publications from 2017 through 2021, with 32 relevant papers published in 2021 in comparison to the 5 relevant papers in 2017, with the number of publications recorded for 2018, 2019, and 2020 being 9, 14, and 20, respectively.

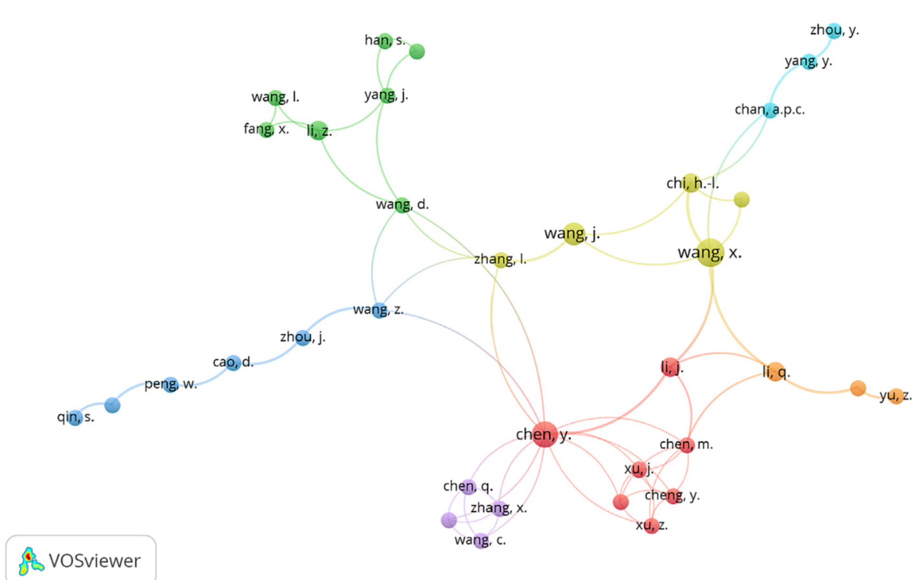

Fig. 5. Network of co-authorships.

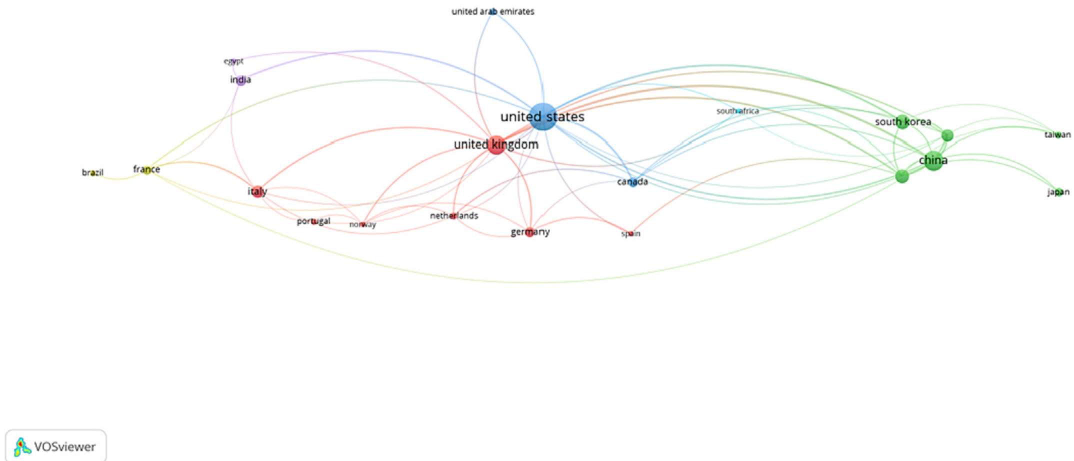

Fig. 6. Network of Collaborations by Country.

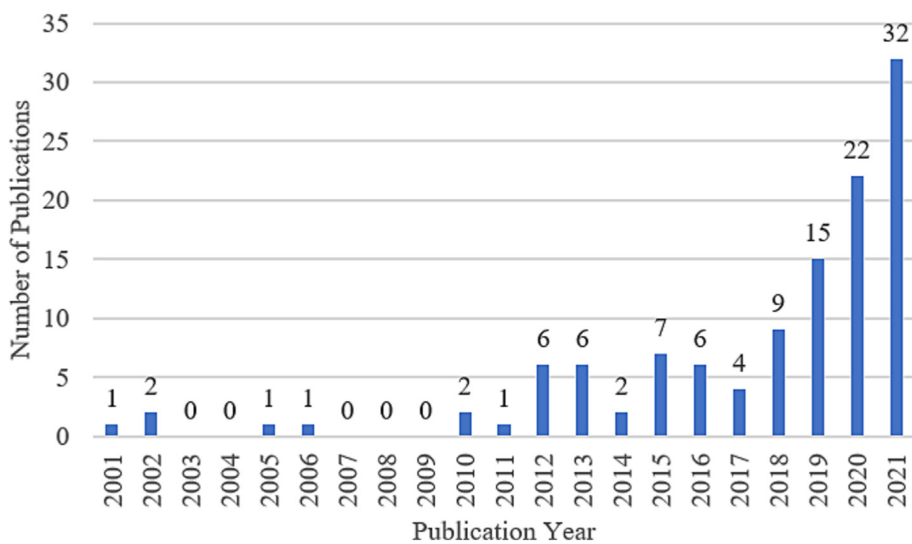

Fig. 7. Distribution of publications per year.

Overall, there has been an increase in the interest of researchers on the application of ImTs for construction OSH management as 32 papers were published in 2021, which is huge progress when compared to the single paper published in 2000. One of the 32 papers published in 2021 is 'Classification of construction hazard-related perceptions using: Wearable electroencephalogram and virtual reality' (Jeon & Cai, 2021), which investigated the feasibility of hazard identification on construction sites with the use of a developed EEG classifier based on experiments conducted in an immersive VR environment in order to address the continuous emergence of new hazards as construction activity progresses. Another study conducted in 2020 titled 'How Sensation-Seeking Propensity Determines Individuals' Risk-Taking Behaviours: Implication of Risk Compensation in a Simulated Roofing Task' (Hasanzadeh et al, 2020a) was conducted with a MR roofing simulation to understand the reason the level of safety intervention tends to make construction workers modify their risk-taking behavior. A significant study amongst the literature published in 2019 is the human-subject experiment conducted using a multi-user VR system and motion tracking device to investigate the social learning behavior of construction workers in the paper titled 'Impact assessment of reinforced learning methods on construction workers' fall risk behaviour using virtual reality' (Shi et al., 2019).

4.1.5. Distribution of publications by location of study

Fig. 8 shows the number of articles across different locations of the world on the application of ImTs for construction OSH management. This was obtained from the institutional address or affiliation of the corresponding authors of the included publications. As seen in Fig. 8, different studies on the application of ImTs for construction OSH management were conducted in at least 27 countries around the world between 2001 and 2021, with the United States conducting the highest number of studies with 44 publications. This indicates that the United States is the biggest contributor to the studies on the applications of ImTs for construction OSH management. The United Kingdom is the second biggest contributor to the applications of ImTs for construction OSH management with nine publications, while Australia, China, and Hong Kong contributed seven publications each. This confirms 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). In addition, Korea had six publications, while Canada and South Korea had four publications each, with Italy and UAE having three publications each. Finland, Iran, Israel, Malaysia, Spain, and Sweden contributed

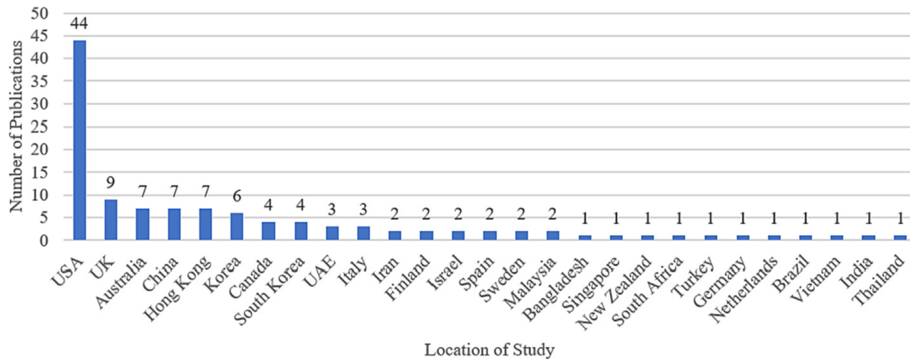

Fig. 8. Distribution of Publications per Location of Study.

two publications each, while Bangladesh, Brazil, Germany, India, Netherlands, New Zealand, Singapore, South Africa, Thailand, Turkey and Vietnam contributed a single paper each.

One of the 44 papers conducted in the United States which is titled 'Predicting workers' inattentiveness to struck-by hazards by monitoring bio signals during a construction task: A virtual reality experiment' (Kim et al., 2021) was based on a feasibility study involving the combination of the use of eye tracking sensors, EEG devices, and machine learning techniques in an immersive virtual environment to predict when construction hazards will be successfully recognized. In another UK-based study conducted by Bosché et al. (2016), the authors aimed to address the challenges of construction safety training by developing a novel mixed reality system that allows training within challenging site conditions to eradicate OSH risks in the construction industry.

4.1.6. Distribution of publications by journal titles

Table 2 presents the distribution of the articles included from all three databases by the titles of journals. The SLR revealed that 53 journals have published research and review articles related to the application of VR, AR, and MR for OSH management in the construction industry. As depicted by Table 3, 'Automation in Construction,' 'Journal of Construction Engineering and Management,' and 'Advanced Engineering Informatics' are the three journals with the most publications with 19, 9, and 6, respectively. 'Construction Innovation,' 'Engineering, Construction and Architectural Management,' and 'Safety Science' recorded equal number of articles with five each. Each of these aforementioned journals have produced several articles that have immensely contributed to the emergence and understanding of the concepts of technology-driven OSH management within the construction industry. For instance, the article titled *"Comparison of ironworker's fall risk assessment systems using*

Table 3
Distribution of Published Papers by Journal Titles.

Journal Title	Number of Published Papers
Automation in Construction	19
Journal of Construction Engineering and Management	9
Advanced Engineering Informatics	6
Construction Innovation	5
Engineering, Construction and Architectural Management	5
Safety Science	5
Journal of Applied Science	4
Buildings	3
Construction Management and Economics	3
International Journal of Environmental Research and Public Health	3
Journal of Computing in Civil Engineering	3
Journal of Information Technology in Construction	3
Sustainability	3
Accident Analysis and Prevention	2
Applied Ergonomics	2
ArXiv	2
International Journal of Engineering Education	2
Procedia Engineering	2
Visualization in Engineering	2
Advances in Civil Engineering, Cognition, Technology & Work, Computers and Education, Education Sciences, Electronics, Engineering Construction and Architectural Management, Engineering Journal, Ergonomics, Facilities, Frontiers in Robotics and AI, IEEE Multimedia, IEEE Transactions on Visualization and Computer Graphics, Infrastructures, Injury Prevention, International Journal of Construction Management, International Journal of Engineering, Transactions B: Applications, International Journal of Injury Control and Safety Promotion, International Journal of Occupational Safety and Ergonomics, Journal of Building Engineering, Journal of Civil Engineering and Management, Journal of Civil Engineering Education, Journal of Intelligent & Robotic Systems, Journal of Management in Engineering, Journal of Mechanical Science and Technology, Journal of Professional Issues in Engineering Education and Practice, Journal of Safety Research, Journal of Systems Architecture, Organization Technology and Management in Construction, Proceedings of the Institution of Civil Engineers: Civil Engineering, Proceedings of the International Conference on Information Visualisation, Safety, Structure and Infrastructure Engineering, Visual Computer, Workplace Health & Safety	1
Grand Total	**117**

an immersive biofeedback simulator" (Habibnezhad et al., 2021) is a significant paper identified from the 'Automation in Construction' journal, which evaluated the fall risk of ironworkers with the use of a reliable and responsive VR simulator.

Another paper from the 'Journal of Construction Engineering and Management' is "*Productivity-Safety Model: Debunking the Myth of the Productivity-Safety Divide through a Mixed-Reality Residential Roofing Task*" (Hasanzadeh & de la Garza, 2020), whereby an immersive mixed reality environment was used to simulate a roofing task, so as to investigate whether the alleviation of task-demands resulting from safer construction site conditions actually causes fall risks to be underestimated. Similarly, a notable publication from 'Advanced Engineering Informatics' journal titled "*Evaluating the attitudes of different trainee groups towards eye tracking enhanced safety training methods*" (Comu et al., 2021) monitored the eye movements of construction safety trainees during VR-based safety training method and traditional safety training methods to understand the attitudes as well as the knowledge retention levels of the trainees toward the training provided.

4.2. State of application of immersive technologies for construction occupational safety and health management

A typical construction site is an embodiment of highly diverse workers from different organizations, with different skill levels and safety cultures. In addition to inherent risks posed by this diversity, numerous high-risk and often complex tasks must also be performed in parallel by different workers within close proximities, which in turn heightens the overall likelihood of unwanted events (Hou et al., 2021). Although conventional OSH management regimes such as PPEs, safety trainings, toolbox talks, and safety inductions are well-established at construction sites, their proficiencies are still undermined by the poor safety record across the industry. It is therefore essential to further explore how recent advancements in technology can be used to strengthen existing approaches, of which industry 4.0 technologies seems to offer complementary alternatives. However, prior to implementing any new approaches, it is imperative to adequately understand the limitations of the existing body of knowledge. Therefore, this SLR focuses on how ImTs as a suite of industry 4.0 has been applied in construction OSH management and how other industry 4.0 technologies complement ImTs in construction OSH management.

4.2.1. Occupational safety and health issue/area addressed by immersive technologies

The popular OSH areas that the reviewed literature focused on are hazard identification and visualization, training and education, risk perception and assessment, design for safety, and general safety. These areas were selected based on the analytical framework adopted in this study as shown in Table 2. The distribution of these areas across the reviewed articles is shown in Fig. 9.

a. Hazard identification and visualization

The uniqueness of every construction project makes it difficult to identify all possible OSH risks, but the use of immersive virtual reality environment can provide a visualization of construction site conditions, thereby making hazard identification easier before commencement of project (Azhar, 2017). Hazard identification is essential for both the safety management team and construction workers (Li et al., 2012b). Shafiq and Afzal (2020) noted that it has become necessary to make use of VR for the improvement of safety in construction, as the conventional methods of instilling effective and practical hazard identification safety knowledge is inefficient. Shafiq and Afzal (2020) also noted that a CAVE system can be used for identification of hazards. Examples of hazards that can be found in the construction industry are: dismantling of tower crane before workers leave the area; working on construction activity without wearing appropriate personal protective equipment (PPE); and building platforms without appropriate fencing (Li et al., 2012b).

One of the identified studies on hazard identification was by Kim et al. (2017), which proposed a vision-based hazard avoidance system for the prevention of accidents by allowing workers to identify hazards through the rendering of augmented hazard information on a wearable device. However, the information rendered by this AR system (consisting of a vision-based site monitoring module) rendered the construction site in a planar form, thereby limiting the identification of other important hazards by workers (Kim et al., 2017). An approach that can be used to address the planar view of the construction sites was observed in a study by Eiris et al. (2018), which involved the development of an augmented 360 degree panorama of reality (PARS) that provides a true-to-reality view of construction sites for effective hazard identification. Subsequently, the participants of this study experienced ease in

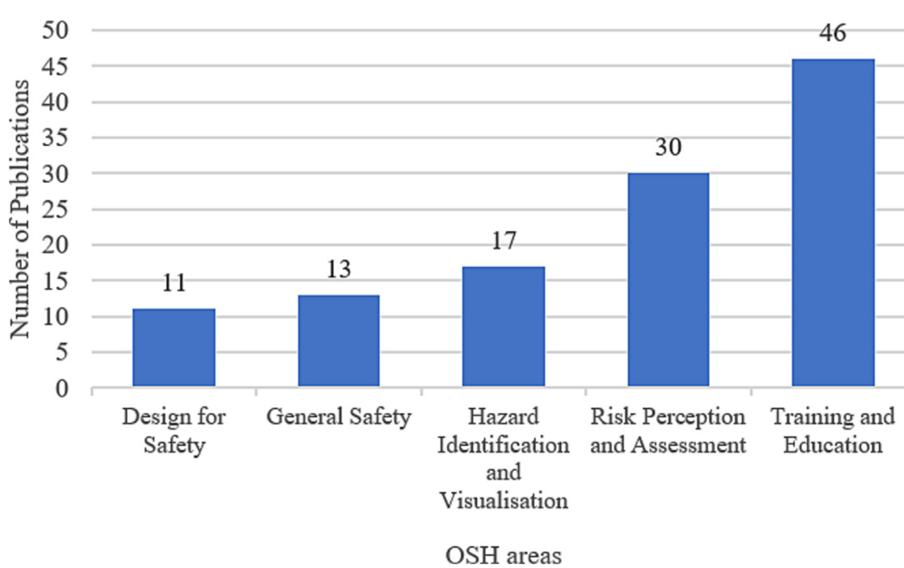

Fig. 9. Distribution of publications within construction OSH areas.

the operation of the system while it assisted them to locate hazards in the panoramic scenes (Eiris et al., 2018). In another dimension, the planar view of construction sites by the vision-based avoidance system can also be addressed with the approach used in a study by Afzal and Shafiq (2021) which involved the application of 4-dimensional (4D) building information models (BIM) and VR. It was observed that VR and 4D-BIM was used for the 4D simulation of construction sites (easy to use and provided the real-life experience of a construction site without actually being in a site), which assisted in hazard identification of workers (Afzal & Shafiq, 2021). A similar study conducted by Teizer et al. (2013) presented a 3-D view of primarily steel erection tasks with the application of location tracking sensors and VR for the effective identification of hazardous activities by steel workers, and it resulted in the effective identification and visualization of hazards. In addition, three case studies conducted by Azhar (2017) demonstrated that contractors can use 4D simulations, BIM models, and VR environment to visually identify hazards. This could assist in the development and communication of plans for mitigating the identified hazards amongst construction workers (Azhar, 2017). This could be more effective in addressing hazards, especially when compared to two dimensional (2D) drawings, because these digital tools closely simulate actual jobsite conditions (Azhar, 2017).

Another alternative approach in the application of ImTs for hazard identification and visualization was observed in a study by Lucena and Saffaro (2020), which involved the exploration of a virtual construction site by construction managers. The construction managers had to mention the hazards they identified to the instructors as the VR technology used provided visual stimuli to them, thereby making it easier to detect dangerous situations intuitively (Lucena & Saffaro, 2020). A similar approach involving the walkthrough of workers in a virtual construction site for hazard identification was adopted in a study conducted by Hadikusumo and Rowlinson (2002). The workers also selected appropriate precautions to the identified hazards for the prevention of accidents (Hadikusumo & Rowlinson, 2002).

b. Training and education

Training and education is a crucial aspect of OSH management, owing to proven instances whereby attitudes, personal characteristics, workplace climates, and organizational cultures have been enhanced through knowledge. Ahmed (2019) noted that safety training and education is a key factor in the promotion of a safe and healthy working environment in the construction industry. One of the most effective ways of improving construction OSH performance is by safety training (Li et al., 2012b). This is perhaps why 39% of studies focused on addressing construction safety training using ImTs as depicted in Fig. 9. Despite the significant importance of safety education for the improvement of safety performance in the construction industry, there is very limited emphasis on safety within the curricular of most of the programs delivered at mainstream institutions of higher learning (Pham et al., 2018). Xu and Zheng (2021) attributed the occurrence of preventable accidents in the construction industry to a lack of experiential training on OSH and highlighted that the occurrence frequency of accidents can be immensely reduced by enhancing the safety awareness of construction site workers through VR-based technologies. The conventional methods of safety education at the few tertiary institutions that offer them have been termed inefficient, due to their inability to adequately replicate or mimic real-life experiences (Le et al., 2015). The conventional methods of safety education consist mainly of lectures, presentations, and video training, which are economical but not necessarily fostering employee engagement and/or knowledge retention. On-site or on-the-job equivalents to safety training have been described as far more engaging, but their huge costs and potential to interrupt industrial operations make them the least preferred option by some employers (Joshi et al., 2021). This is perhaps the reason for the upward trend in publications related to technology-enhanced OSH management as depicted by Fig. 7. For example, Le et al. (2015) conducted a study that indicated that the developed prototype of a collaborative VR-based system for construction safety education through dialogic learning and social interaction in a virtual 3D environment has great potential to improve construction safety education. Le et al. (2015), however, recommended that a study on the application of the integration of collaborative VR technology and AR for construction safety education should be considered. Another study conducted by Le et al. (2015) then proposed a framework that combines mobile-based VR and AR to create virtual scenarios of real accident occurrences for delivering safety education to students and discovered that the integration of VR and AR with mobile computing can address the limitations of the conventional construction safety education. Bhagwat et al. (2021) also conducted a study on mobile-based VR system that was developed as a game-based safety module. Bhagwat et al. (2021) realized that students preferred the mobile VR system because it provided realistic and immersive experience, while construction professionals prefer a virtual tour-based safety module because of its ease of operation, cost-effectiveness, and time savings. Getuli et al. (2021) used a different approach as the integration of building information modelling (BIM) and VR for construction safety training was proposed. A safety training protocol based on BIM-enabled VR activity simulations was used in tackling the complexities associated with rendering safety trainings. The integration of BIM and VR for safety training by Getuli et al. (2021) addressed the technological aspects, thereby allowing for a coherent flow of information from the BIM environment to the VR simulated environment, and it also alleviates some of the methodological issues, especially those related to aiding decisions on training needs analysis and scheduling.

Xu and Zheng (2021) developed a VR safety training platform that is comprised of a 3D modeling stage, VR environment rendering process, and the training system program design. It was discovered that the developed safety training platform was more effective in the training of workers when compared to the conventional safety training methods, but the platform could not enable free navigation of the workers in the real world during the training session, thereby reducing the realism of the immersive experience (Xu & Zheng, 2021). This navigation limitation could, however, be addressed by the method used by Adami et al. (2021) which involved the use of a VR treadmill in the virtual dynamic construction site for navigation of workers. Seo et al. (2021) focused on the use of VR technology for the implementation of an experiential safety education system in the electrical construction trade. The study indicated that the VR-based safety education system for electrical construction site workers could improve their learning outcomes, and provides an environment for learning in risky scenarios that could be difficult in lecture-based methods (Seo et al., 2021). Joshi et al. (2021) focused on a different construction trade and developed a VR safety training module for the precast concrete industry with the aim of assisting precast concrete industry workers in understanding safety protocols more accurately and to avoid more accidents. Joshi et al. (2021) discovered that the VR training module made workers highly motivated, had the potential to help workers retain and understand more information, and also had the potential to reduce the number of accidents on sites. A study conducted by Nykänen et al. (2020) revealed that VR-based construction safety training has stronger impacts on self-confidence, safety motivation, and safety-related outcome expectancies when compared to conventional lecture-based alternatives.

c. Design for safety

Construction sites are very complex and dynamic work environments, which makes the processes required for ensuring the safety of their designs extensive but crucial for averting accidents (Côté & Beaulieu, 2019). In recent times, concepts such as design for safety (DfS) have gained significant traction toward ensuring that construction designs prioritize accident prevention (Manu et al., 2019). Design for safety is also known as prevention through design, safety through design, and safety by design (Farghaly et al., 2021).

Designers can play a huge role in the improvement of construction OSH management with VR, a very useful tool, used in assisting designers make appropriate decisions leading to safety during the execution of construction works (Sacks et al., 2015). Sacks et al. (2015) emphasized the usefulness of VR to OSH management in construction, especially their ability to support the decision-making process of designers in the execution of construction work by conducting pilot tests on designers and construction managers who both have knowledge on safety issues in design and construction. The study conducted on designers and construction managers by Sacks et al. (2015) involved the interaction of these participants in a virtual construction site and it was discovered that dialogue makes safety issues in designs more identifiable and clearer, especially for designers. In another closely related study, Hadikusumo and Rowlinson (2002) proposed a design-for-safety-process (DfSP) that integrates VR functions, virtual construction components and processes, and DFSP database. The DfSP allows construction practitioners to perform a walk-through of the virtual environment equivalent to their construction sites to proactively identify inherent hazards, so that appropriate mitigating measures can be implemented to avert catastrophic accidents (Hadikusumo & Rowlinson, 2002).

Yu et al. (2019) focused on combining the features of VR and AR technologies with BIM, big data processing terminals, and wearable devices for issuing reports on the dynamic safety predictions and danger warnings. Another study focused on the integration of BIM with emerging digital technologies such as global positioning system (GPS), laser scanning, sensors, VR, AR and photogrammetry for construction safety and high-rise buildings with promising results of the integration of BIM with digital technologies for construction safety in high-rise buildings (Manzoor et al., 2021). Another study presented the potential of using virtual design construction (VDC) tools such as VR, AR, BIM, and geographic information systems for the improvement of safety on construction sites in Gulf Cooperation Council (GCC) countries (Shafiq & Afzal, 2020). The study indicated that the design of emergency and evacuation plans and fall-hazard prevention strategies are the most effective applications of the VDC tools in the improvement of construction site safety (Shafiq & Afzal, 2020).

d. Risk perception and assessment

An immersive MR environment was developed and integrated with real-time head and ankle tracking sensors to monitor the reactionary behavioral responses of building construction students with industry experience during the execution of roofing tasks, under three experimental scenarios: (1) task with no fall arrest system; (2) task with fall-arrest system; and (3) task with fall-arrest system and guardrail (Hasanzadeh et al., 2020b). Based on the risk assessment conducted on the participants of this study while installing asphalt shingles, Hasanzadeh et al. (2020b) observed that the safety complacency of participants increased as the level of safety protection offered increased (i.e., risk-averseness of participants reduced as they moved from Scenarios (1) – (3)). In another study, Pooladvand et al. (2021) aimed to enhance safety inspections and planning routines of on-site lifting operations by proposing a framework that uses VR technology to proactively assess the risks involved in routine lifting operations of mobile cranes prior to the commencement of actual tasks to better improve the understanding of inherent failure modes associated with lifting of heavy modules. The outcomes of the assessment broadened the perception of risk and the lifting process of users of the mobile crane in the virtual jobsite created with a computer game engine (Pooladvand et al., 2021).

The risk perception of forklift operators during the operation of forklifts was assessed with the use of a VR forklift simulation model for various subtasks such as driving, loading, unloading reversing, and turning (Choi et al., 2020). It was revealed that the different subtasks affect the level of risk perceptions of the forklift operators differently, depending on the complexity of such tasks. Choi et al. (2020) then suggested the use of additional control measures such as sensing devices and situational signifiers for the improvement of the risk perception of forklift operators. Another study involved the use of immersive MR construction site environment and real-time head and ankle-tracking sensors to simulate a roofing activity in order to monitor and assess the risk perception of workers while performing roofing activities with the use of fall protection (Hasanzadeh et al., 2020b). Upon the conclusion of the study, Hasanzadeh et al. (2020b) asserted that roofing workers perceive less risk because the usually use fall protection, which allows them to be more reckless when performing roofing activities and take more risks.

e. General safety

Akinlolu et al. (2020) conducted a bibliometric review on industry 4.0 technologies including VR for construction health and safety management and the review revealed that the application of these technologies has improved the health and safety issues in the construction industry. It was also observed that there is an underrepresentation of the application of industry 4.0 in Africa in the literature when compared to other continents (Akinlolu et al., 2020). Li et al. (2018), however, conducted a critical review focusing mainly on VR and AR in addressing construction safety issues in academic studies. It was discovered that academic studies on VR and AR for construction safety have been conducted from various views, including safety enhancement mechanisms and technology characteristics with proven efficiency of VR and AR in the general construction safety areas (Li et al., 2018).

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

This SLR has revealed that the main types of OSH hazards addressed by the use of ImTs are struck-by hazards (Oh et al., 2019), electrocution (Zhao & Lucas, 2015; Zhao et al., 2016), working at height (Habibnezhad et al., 2021), caught-in/between (Pham et al., 2019), and slips/trips (Afzal & Shafiq, 2021). This is perhaps why several studies are seeking remedies through various initiatives, including the development and evaluation of advanced safety algorithm to tackle collisions between an excavator on site and nearby workers using real-time simulations with VR (Oh et al., 2019). The VR technology that simulated excavator movement showed that the developed advanced safety algorithm can prevent workers from getting struck by excavators, thereby reducing fatal accidents on construction sites (Oh et al., 2019). Zhao and Lucas (2015) proposed the use of VR simulation for safety training to reduce fatalities and accidents caused by electrocution, owing to previously reported effectiveness of VR approaches for construction safety trainings. The leading cause of injuries and deaths on construction sites is falling from height and this prompted Habibnezhad et al. (2021) to examine a VR simulator that integrates several tracking devices attached to key parts of the body for assessment of fall risk of ironworkers. This is perhaps why the number of publications that have focused on fall hazard as depicted in Fig. 10 is high. Alternatively, in order to address fall hazards, Bosché et al. (2016) conducted a study on how to make use of MR technology to provide exposure on conditions surrounding working at height to trainees, with positive feedback from the test subjects regarding the effectiveness of the MR system on the preparation of trainees for working at height conditions that they will later experience in a real construction site.

The experiments were conducted on 12 healthy adults and highlighted that a more effective performance is achievable through the VR simulator, especially in the upper-limb stability assessment of workers at height when compared to traditional VR systems (Habibnezhad et al., 2021). Pham et al. (2019) proposed an interactive augmented photoreality (iAPR) platform that provides safety education for construction students on hazards such as caught-in/between, electrocution, struck-by and fall. The proposed iAPR platform showed effectiveness in enhancing construction hazards investigation knowledge and skills. The effectiveness of a four-dimensional (4D) BIM and VR system developed for the simulation of construction site to train a multilingual construction crew on construction safety, with emphasis on the avoidance of slips, trips, and falls was also evaluated by Afzal and Shafiq (2021).

4.2.3. Types of occupational safety and Health conditions addressed by immersive technologies

Typical construction sites are characterized by different classes of OSH hazards, which may impact the safety, health and well-being of employees in different ways. For instance, some construction workers are exposed to different levels of noise, which may lead to hearing losses and in some cases impact their mental health (Lu & Davis, 2016). A possible way of addressing noise hazard can be applying the use of sound effects in a virtual environment to investigate the safety decision making of construction workers on construction sites with the use of a mini audio player, computer, and headphones as seen in the study by Lu and Davis (2016). A different study focused on mental fatigue as another OSH condition in the construction industry, as it greatly affects attentional resources and impairs cognitive capacity (Tehrani et al., 2021). The study utilized VR environment and EEG signals for the assessment of mental fatigue of construction workers that are working at heights and discovered that the exposure of construction workers to height caused an increase in the levels of mental fatigue in them (Tehrani et al., 2021).

Huang et al. (2021) designed six virtual scenarios of different types of commonly encountered construction site injuries: electrical injury, injuries caused by object impact, mechanical injury, injuries caused by foundation collapse, injuries caused by confined space, and injuries caused by falling. Some of the virtually simulated scenarios involved trainees inserting damaged plugs into a distribution box so as to cause electrical injury; or trainees getting hit by falling objects such as steel pipes; or trainees walking within the operating radius of a functioning excavator to induce mechanical injury; or trainees working on foundation slabs with cracks as well as deep wells with limited oxygen to induce falls and asphyxiation (Huang et al., 2021). In order to understand the impact of fear on postural stability of ironworkers, Habibnezhad et al. (2019) developed a virtual construction site that exposed ironworkers to extreme height and a structural beam moving toward them while also measuring the heart rate of the participants. It was observed that height had a negative impact on postural stability, while self-judged fear decreased postural instability both in the presence and absence of height (Habibnezhad et al., 2019). In another closely-related study, Hsiao et al. (2005) measured the gait patterns, cardiovascular reactivity, and the walking instability measurements of both experienced and inexperienced construction workers performing tasks on real planks on a virtual scaffolding. It was observed that the novice workers were more unstable as compared to construction workers, and they also had higher mean strides width than the experienced workers, which indicates higher level of falls for the novice workers (Hsiao et al., 2005).

4.2.4. Nature of construction activity and stage at which immersive technologies are applied

Construction hazards occur at different construction activities and stages of asset life cycle and the effectiveness of the mitigating measures implemented could be dependent on the understanding of such activity and stages. Some of the focus areas of construction OSH management studies include road construction (Kim et al., 2021), railway construction (Xu & Zheng, 2021), multi-storey buildings (Lucena & Saffaro, 2020), roofing (Hasanzadeh et al., 2020b), reinforcing bar (Abbas et al., 2020), steel erection (Teizer et al. 2013), and scaffolding (Tehrani et al., 2021). Kim et al. (2021) developed a VR environment for the simulation of road con-

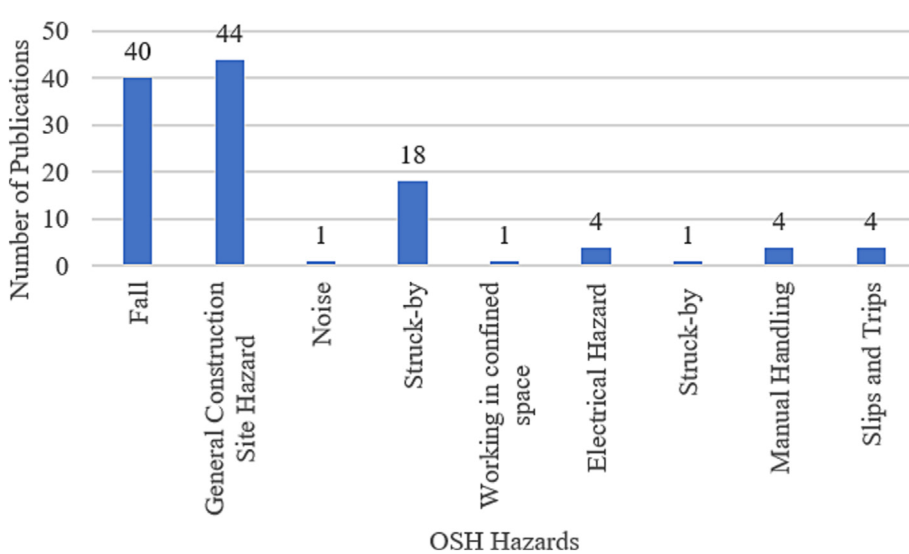

Fig. 10. Distribution of publications with the OSH hazards addressed.

struction works that was used to investigate how repeated exposure to hazards in road construction tasks affects the vigilant behavior of worker operations. Kim et al. (2021) observed a decline in the vigilant behaviors of workers in response to approaching vehicles over time. Xu and Zheng (2021) focused on another area of construction by conducting a pilot study of a railway station under construction that involved several machineries working together for level crossing removal and site rebuild. The developed immersive and interactive multiplayer VR platform through this study was found to be effective in the safety training of workers. A mobile-based VR technology was used for the simulation of two multi-story buildings consisting of six floors in order to present different ways for the exploration of virtual construction sites for hazard identification using low-cost devices (Lucena & Saffaro, 2020). It was observed that one of the exploration methods (which required strict guidelines to workers) was more effective than the other exploration method (which required no guidelines in the hazard identification of workers; Lucena & Saffaro, 2020).

However, the majority of research studies on the application of ImTs for construction OSH management have concentrated on the design (Hadikusumo & Rowlinson, 2002; Shafiq & Afzal, 2020; Afzal & Shafiq, 2021) and the construction phases (Li et al., 2006; Kim et al., 2021), with a few on the demolition phase (Adami et al., 2021) as shown in Fig. 11. This could be because the design phase offers the greatest ability to mitigate adverse OSH outcomes that manifest during the construction phase. It could also be due to the difficulty in the reproduction of demolition scenarios in a virtual environment. The SLR conducted by Farghaly et al. (2021) on BIM and VR harmonization for construction OSH management recognized that designers have ample opportunities to lower risks during construction and maintenance, through the implementation of design for safety principles. The study, however, identified three main challenges regarding the application of VR and AR for design for safety, which are inadequate quality of design models, scalability, and construction sequencing.

4.2.5. Hierarchy of control

Hierarchy of controls (which comprises of elimination, substitution, engineering controls, administrative controls and personal protective equipment (PPE)) have been implemented for OSH management in the construction industry (Nnaji & Karakhan, 2020). For example, it was observed that administrative control was implemented by Comu et al. (2021), who proposed VR safety training of workers on hazard identification in order to prevent injuries and fatalities. Administrative control, which can be defined as the various established policies such as ensuring adequate safety trainings in order to promote safety in a work environment (Environmental Health and Safety, 2017), was also implemented by Kim et al. (2021). Kim et al. (2021) examined the efficacy of VR technology for the mitigation of a decline in the level of risk perception of construction workers. In another study that tried to eliminate hazards, VR tools were used by designers and builders to decide on alternative designs and construction scenarios (Sacks et al., 2015). Fig. 12 shows the distribution of articles based on the hierarchy of control.

4.2.6. Complementary industry 4.0 technologies for construction OSH management

Other industry 4.0 technologies used to complement ImTs for construction OSH management are robots (Adami et al., 2021), big data and analytics (Lee et al., 2020), sensors (Huang et al., 2021), and BIM (Khan et al., 2021). The simulation of a virtual environment for the authentic learning of construction safety and health was proposed for undergraduate students and practitioners with random forest, a machine learning technique used for the analysis of the feedbacks from the undergraduates and practitioners (Lee et al., 2020). It was then discovered that the authentic learning characteristics can be grouped into three (authenticity, group work, and guidance) with these three factors being more important than the role (student or practitioner) (Lee et al., 2020).

Khan et al. (2021) conducted a review on the integration of VR, AR, and MR with BIM in the construction industry for various domains including construction health and safety, construction monitoring, and training and education with health and safety reaping benefits from these ImTs. Construction workers with the use of VR-based training experienced different strategies of demolishing a concrete block with a robot to determine which of the strategies was safer and more effective (Adami et al., 2021). To address the issue of restricted field of view and the non-negligible weight of augmented reality devices such as HMDs, heavy helmets or goggles, a mobile projective AR (MPAR) system (which consists of a portable projector, a camera and a laptop) is mounted on mobile collaborative robots and is used to project virtual information on planar or three dimensional (3D) physical surfaces (Xiang et al., 2021). The MPAR also promotes human-robot collaboration on construction sites (Xiang et al., 2021).

4.3. Challenges involved in application of immersive technologies for construction occupational safety Health management

Although, ImTs have the potential to revolutionize OSH management within the construction industry, especially owing to their ability to transfer knowledge without necessarily exposing participants to real-life operational hazards, some challenges associated with ImTs have been raised by different studies, of which the most prominent ones will be discussed here.

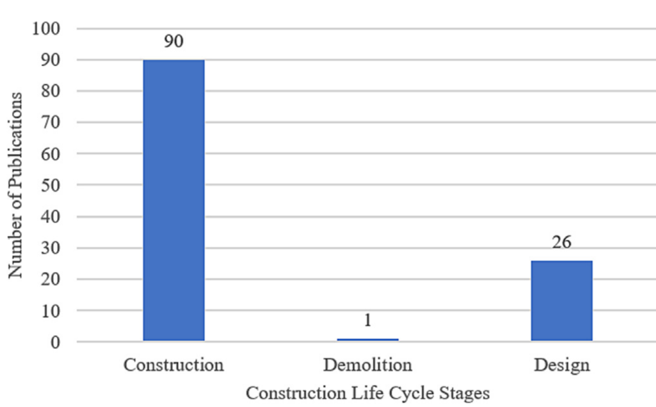

Fig. 11. Distribution of publications with the construction life cycle stages.

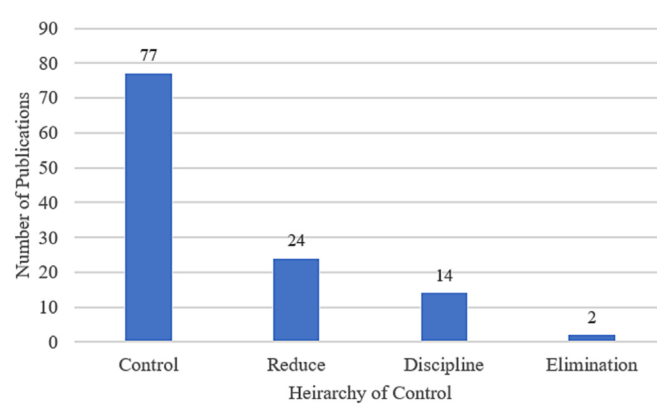

Fig. 12. Distribution of publications with the hierarchy of control.

One of the challenges associated with ImTs for construction OSH management include simulation sickness experienced by users of these technologies, especially within virtual environments. For example, some of the construction professionals that participated in a study by Bhagwat et al. (2021) complained of dizziness, headache, eye stress, and discomfort, especially for those that wore spectacles while using a head-mounted display. This was also validated by Joshi et al. (2021) when they reported that a small fraction of the respondents that participated in their VR-based experiments complained of some minute symptoms of simulation sicknesses. Han et al. (2021) further buttressed these findings when they stated that not all the participants of their VR experiments felt comfortable wearing the devices associated with virtual tasks.

Another challenge with the application of ImTs for construction OSH management is the level of restrictions in the navigation of users of a virtual environment. Participants of a VR training could not generate exact replica movements like they would in real life, which sometimes creates an adverse effect on the level of realism of the immersive experience (Xu & Zheng, 2021), and may in turn lead to participants undermining the seriousness of the knowledge acquired. In a different but related study, users of a virtual safety assessment system also complained of the complexity of navigation within the system (Li et al., 2012b). Although, Xu and Zheng (2021) proposed the use of a 360-degree walking pad, which can also be referred to as a treadmill, for the actual movement of workers, it is, however, expensive to purchase and setup for use to aid movement of participants in a virtual environment. Users of a virtual environment complained of difficulty in navigating through the environment due to abundant rendering and animation, which made the users confused and distracted (Xu & Zheng, 2021). Similarly, the discrepancy in the movement of users of ImTs and the virtual animations had an adverse effect on the sense of presence in a virtual environment (Shi et al., 2019). Users of virtual environments related to working at height were prone to overestimating the actual altitude of a real, physical height as participants were observed adjusting their stride lengths at a simulated height when compared to ground level (Hsiao et al., 2005).

Another challenge associated with the use of ImTs is effectiveness of communication, as seen in the VR-based system for construction safety training and education developed by Seo et al. (2021). The system was a one-man system, thereby making it difficult for field officials to interact with one another, so communications with co-workers, safety managers, and field managers using radio were not considered. It was also difficult to conduct safety training for a large number of construction workers as the motion sensor used to detect movement of people within the environment could only detect two people (Seo et al., 2021).

The cost and duration of the implementation of ImTs for construction OSH management is another prominent limitation for ImTs, especially as Eiris et al. (2020) observed that the total replication of hazards in a virtual construction site was impracticable as it required high computational costs and long development times to assemble observable hazard scenarios in a virtual construction site. Also, Afzal and Shafiq (2021) asserted that the development of a virtual environment for a new construction project can be time-consuming, while educators raised concerns regarding the feasibility of implementing a virtual safety education system due to financial costs of the development of a virtual safety education system (Pedro et al., 2016). The cost and development time limitation could be due to what Abbas et al. (2020) realized about construction projects with regard to their uniqueness and complexity, which makes it challenging to replicate construction site experience in a virtual environment. In addition, the difficulty in simulating a real construction site could also lead to a lesser sense of presence and feeling of realism in a virtual construction site, which could have a huge adverse effect on the OSH performance of construction workers and students using the developed virtual construction site. The real world construction sites are complex with unpredictable hazard situations (Shi et al., 2019), and therefore there could be latent hazard conditions yet to be addressed in academic studies with the application of ImTs. Furthermore, there is a lack of manpower needed for the development and implementation of ImTs, as according to Ahmed (2019), there is lack of expertise and technicians for the development, implementation, and maintenance of ImTs.

Inconsistency in the level of detail for an entire simulation of a virtual environment is another challenge in the use of ImTs, as it has adverse effects on the review of the entire building by safety experts and project manager as some critical areas of safety planning may be unintentionally ignored for components with lower level of details (Afzal & Shafiq, 2021). The MPAR system designed by Xiang et al. (2021) to address the discomfort experienced by users of augmented reality devices experienced challenges of image brightness caused by other light sources such as sunlight, which resulted in less visible virtual information projected onto planar or 3D surfaces. Finally, tutors are worried that the mobile devices used in the implementation of mobile-based VR and AR framework proposed by Le et al. (2015) can be a distraction to construction safety students in the classrooms.

5. Conclusions

This study conducted a comprehensive systematic review on the applications of ImTs for the effective OSH management in the construction industry. This study also presented the results of the bibliometric analysis on the broad body of literature on the applications of ImTs for construction OSH management. It has been observed that various research has been conducted on the applications of ImTs for the identification of hazards, training and education, design for safety, risk perception and assessment, and general safety. These studies were conducted with the aim of addressing various types of hazards including working at height, lifting of heavy loads, electrical hazards, and caught in-between objects to avoid injuries and fatalities. The applications of ImTs for construction OSH management has been observed from the literature body to have a huge positive impact on the management of OSH in the construction industry. It has, however, been discovered that there has been a low level of transition from research to industry practice.

Some studies (e.g., Sacks et al., 2013; Afzal & Shafiq, 2021; Han et al., 2021) adopted the use of questionnaires to obtain data from the experimental study to measure the effectiveness of the application of ImTs for addressing construction OSH areas, while different statistical techniques were used to determine how effective ImTs are in the improvement of construction OSH management. Alternative tools used for the collection of data are EEG sensor (Noghabaei et al., 2021; Tehrani et al., 2021), eye-tracking sensors embedded in the head-mounted display (Kim et al., 2021), electrodermal activity (EDA) sensor (Kim et al., 2021), and sphygmomanometer (Huang et al., 2021).

Various studies concluded that ImTs have great potential in the improvements of construction OSH management. Other industry 4.0 technologies such as robotics and big data and analytics can be used to complement ImTs to address the poor OSH statistics in the construction industry. It is therefore highly recommended that construction companies seek to make use of ImTs for the OSH management at the different stages of construction, which include the design stage, construction stage, maintenance stage, and demolition stage. Compared to other SLRs on the application of ImTs on construction OSH management, this review focused widely on the application of ImTs, which includes VR, AR, and MR in addressing construction OSH areas, different types of construction OSH hazards, and different types of construction OSH conditions. The above findings can therefore be used to encourage the use of ImTs in the industry to improve the poor OSH situation in the construction industry.

5.1. Study limitations

Some of the papers obtained for SLR in this study may have been left out due to the definition of inclusion and exclusion criteria, which focused mainly on journal articles within Scopus, WoS, and EV databases and written in English language only. The study did not consider other search engines. However, the articles obtained in this study encompass the main body of knowledge in the scope of this study. Nonetheless, future studies could include other databases and other document types.

5.2. Main gaps in existing body of knowledge

Some limitations to the studies conducted on the applications of ImTs for construction OSH management were observed. A common limitation observed in various studies was the sample size, as studies were conducted with relatively small sample size (Lu & Davis, 2016; Din & Gibson, 2019; Hasanzadeh et al., 2020). Many experienced construction workers who are trained to identify hazards are prone to underestimate the gravity of the repercussions of the identified hazards and therefore engage in risky behaviors (Jeon & Cai, 2021).

Users of a virtual construction simulator for investigating the effects of construction sounds on worker decisions were exposed to a short time exposure to construction sounds, with a maximum of 1 hour of sound exposure (Lu & Davis, 2016). The users also attempted to remove the headphones used to simulate construction sounds as the sounds irritated the user (Lu & Davis, 2016). Diego-Mas et al. (2020) discovered that when participants received safety training with the use of virtual reality technology, little training was transferred to jobsites three months after the VR-based training session as the mode of training did not increase the risk perception of workers (Jeon & Cai, 2021). The readiness of tertiary institutions to incorporate safety learning with the use of ImTs in the current syllabus will play a crucial role in construction safety training for students (Le et al., 2015). There is therefore a need to proffer solutions to the numerous challenges in the use of ImTs, such as simulation sickness or huge financial costs. Not every worker requires learning about every hazard (Afzal et al., 2021) and this could result in developing different ImTs-based construction safety training and assessment for different workers, which could be time consuming and expensive.

5.3. Future Research Considerations for ImTs in construction OSH management

- The different measures used in the assessment of the performance of ImTs include simulation sickness, user experience, and system usability, which are predominantly measured via questionnaires (Joshi et al., 2021). The questionnaires are often furnished with simulation sickness scores to ascertain the suitability and safety of a particular immersive technological platform for conducting research studies. There are also presence questionnaires for the evaluation of user experience and system usability scale questionnaire to determine the expectations of users through a system usability score (Joshi et al., 2021). Future research should work on the development of alternative tools for the assessment of the performance of ImTs, which could apply other complementary industry 4.0 technologies such as internet of things (IoT) and big data and analytics and compare the effectiveness of the use of these developed tools' performance assessment with that of the use of questionnaires.
- Although the popularity of studies based on ImTs for construction OSH management is gradually increasing, there are still several construction trades that are yet to be explored, especially glazier, plumbing, carpentry, and welding. These under-represented construction trades occur at high frequencies and volumes on almost every construction site, which in turn heightens their risk priority numbers. They also have inherent hazards that must be addressed for the overall improvement of OSH performance within the trade and in the construction industry. It is therefore imperative that research should be conducted on the applications of ImTs for construction OSH management in these various construction trades.
- Further work should be done to investigate the reason behind a portion of participants experiencing simulation sickness during the use of virtual environment, while another portion of participants do not feel any symptoms of simulation sickness and possibly proffer ways for the reduction or elimination of simulation sickness. It is recommended that larger sample sizes are used to increase the effect of the study and the development of a possible solution to simulation sickness, especially as the sample sizes have also been a common limitation observed in literature.
- There is limited research in the application of ImTs for health-related conditions such as musculoskeletal disorders, which could be caused by the continuous execution of strenuous activities, skin conditions such as contact dermatitis, and skin cancer which could be caused by exposure to harmful substances such as dampened cement or tars or exposure to or sunlight. Further research should be conducted on how VR, AR, and MR can be applied for identification of health hazards, health training, and the risk assessment and control of hazardous substances on construction sites. Further work should also be conducted to determine the level of retention of participants of OSH training with the use of ImTs and to determine the intervals of training to achieve the optimum impact on the level of understanding of the construction OSH trainees and the level of retention of the trainees.
- The OSH training should focus on different construction trades such as the electrical construction trade, glazier, carpentry, masonry, and many more.
- Studies should be conducted on the effects of collaboration amongst construction workers undertaking a task in a virtual environment by developing a platform that enables the interactive control of the ImT system by several construction workers and to switch between viewpoints. This is to ensure a more effective assessment of the risk-taking behaviors of construction workers.
- The accuracy of the calibration of the movement of construction workers and students and the animation in a virtual environment should be improved with further research on more suitable technologies to improve the accuracy of calibration.
- The number of countries around the world that have contributed to the study on applications of ImTs for construction OSH management are few in comparison to the total number of countries worldwide. This finding indicates that the applications of ImTs for construction OSH management are slow-paced globally and are only in the nascent phase. This means that further research studies should be made to promote the applications of ImTs for construction OSH management globally, especially in countries lacking in studies in this area.
- The low visibility issue with the MPAR should be studied to determine possible solutions to the interference by external sources of light such as studies on the application of laser pro-

jectors, as it has been noted from literature that MPAR is one of the possible solutions to the health and safety issues inherent with the use of ImTs.

- There is an urgent need to intervene in the low adoption of the research studies on the application of ImTs for construction OSH management by the industry. It is therefore recommended that studies are conducted to determine possible reasons for the low transition level of study to industry practice of ImTs and proffer possible solutions to these reasons. In addition, the developed ImTs in various studies should be further evaluated and validated sufficiently for industrial application with the use of a larger sample size of construction practitioners, as this could be a factor in making the industry more interested in the adoption of ImTs for construction OSH management. Furthermore, some studies were conducted on students (Lu & Davis, 2016; Jeon & Cai, 2021; Kim et al., 2021; Noghabaei et al., 2021) and to further validate the developed ImTs for construction OSH management, further works should be conducted on these studies by evaluating the performance of the developed ImTs on construction practitioners.
- The financial analysis of the use of ImTs in comparison to traditional methods for the management of different areas of OSH in the construction industry should be conducted to further understand the overall benefits and limitations of using ImTs for construction safety management.
- Finally, to further understand the relationship between the different feelings of construction workers caused by construction sounds and their safety decisions in the virtual environment, further studies should be conducted using different combinations of construction sounds ranging from intermittent sounds, low frequency sounds, to continuous and impulsive sounds.
- From the results of this review, it has been observed that there has been a disproportionate focus on the applications of ImTs of construction occupational safety management as opposed to construction occupational health management. Occupational health management is, however, very critical in the construction industry as there are many occupational health hazards inherent in the industry. It is anticipated that the use of ImTs for occupational health management would further enhance OSH management in the construction industry. This SLR therefore proposes that future studies should be conducted to investigate how ImTs can be used in addressing occupational health hazards and also compare the performance of ImTs with that of the conventional methods of occupational health management. In addition, training has been observed to be an effective method for addressing poor OSH performances. Consequentially, this article puts forward as a proposition that ImTs for occupational health training would be more effective than the conventional methods of training in the construction industry. This, however, requires testing. It is therefore recommended that further studies should be conducted to compare the effectiveness of ImTs for occupational health training to that of the conventional methods of training.

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NA.

Declarations of conflict of interest

The authors declare no conflict of interest.

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