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Review

A Scoping Review on Hazard Recognition and Prevention Using Augmented and Virtual Reality

Tauqeer Faiz [1,2,*], Mark Tee Kit Tsun [2], Abdullah Al Mahmud [3] and Kwan Yong Sim [2]

[1] Department of Computer Science, University of Wollongong, Wollongong, NSW 2500, Australia
[2] School of Information and Communication Technology, Swinburne University of Technology Sarawak, Kuching 93350, Malaysia; mtktsun@swinburne.edu.my (M.T.K.T.); ksim@swinburne.edu.my (K.Y.S.)
[3] Centre for Design Innovation, Swinburne University of Technology, Hawthorn, VIC 3122, Australia; aalmahmud@swin.edu.au
* Correspondence: tfaiz@uow.edu.au

Abstract: Hazard recognition and prevention techniques utilize augmented reality (AR) and virtual reality (VR) technology for immersive training and identification of potential hazards. Currently, no scoping reviews exist specifically on hazard recognition and prevention using AR and VR, which is crucial for forming evidence-based guidelines. This scoping review aimed to identify the use of AR and VR in hazard recognition and prevention, identify research gaps, and provide future recommendations. This Joanna Brings Institute (JBI) approach was used to investigate hazard recognition and prevention with AR and VR interventions. A total of six reliable databases were included: Google Scholar, IEEE Xplore, ACM Digital Library, PubMed, Scopus, and APA PsycNet, focusing on records and publications from the last five years. The review identified 5438 publications, with 22 meeting final inclusion criteria. The major findings include the use of AR and VR for teaching new skills, ensuring health and safety, enhancing realism, developing cognitive skills, improving performance, increasing engagement, and stimulating a sense of presence. Limitations identified include limited or non-diverse sample size, absence of real-world scenarios or contextual learning, inadequate game mechanics, insufficient validation of test results, lack of dynamic game behaviour, insufficient expert inclusion, technology issues, long-term impact assessment, and cost comparisons with traditional approaches. Technological issues have emerged as an additional impediment, limiting the efficacy of AR/VR applications in hazard recognition and prevention. In light of these findings, future research should focus on integrating contextual learning, expert inclusion, sample recruitment, expert validation, long-term impact assessment, and resolving technological challenges to enhance AR/VR applications' efficacy and real-world viability.

Keywords: hazard recognition; hazard prevention; augmented reality; virtual reality; extended reality

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1. Introduction

The term 'hazard' refers to an identifiable situation that is potentially dangerous, posing a threat, danger, or trouble. For example, the presence of massive water bottles near computer equipment in a lab can sometimes constitute a risk [1]. Such hazards may also lead to slippage, particularly if the floor contains any amount of fluid. The purpose of this proposed scoping review is to chart, contrast, and categorize relevant literature on hazard-related environments, with a focus on expanding awareness and anticipation through the use of augmented and virtual realities. A scoping review follows a systematic search of peer-reviewed journals to discover all available evidence relevant to the research question [2].

Hazard recognition and prevention are essential safety management responsibilities, crucial for protecting people and infrastructure from potential disasters [3]. Modern tools like AR and VR have been used to transfer these basic capacities within the working

environment [4]. While these approaches have proven valuable, they are not without limitations [4]. This scoping review aims to investigate the current state of research on hazard recognition and prevention using augmented and virtual reality. Hazard recognition and prevention encompass a broad field, including applications in civil engineering, fire safety, and training older adults in recognizing hazards. Currently, no scoping review provides a comprehensive summary of the latest research in this particular domain. To address this, eight variables were considered: study aim, participants' age range, research questions, field of study, research methodologies used, major findings, study limitations, and settings (geographic locations). Key information was collected and summarized accordingly. The findings of this scoping review will help researchers understand the extent of current literature on hazard recognition and prevention using augmented and virtual reality, the research methodologies adopted in the domain, the hardware tools used for empirical studies, major findings, and the limitations of these studies.

AR and VR technologies are increasingly being used in disaster management training to enhance understanding of dangerous conditions and develop efficient moderation solutions [5]. AR overlays digital information on real-world environments, while VR immerses practitioners in concrete environments through embodied simulations of events [6,7]. The integration of these innovations may further transform the manner in which the prevention and detection of hazards are conducted. The prospects of using AR and VR in training for disaster management are gradually beginning to appear as the very existence of the digital environment evolves [8,9]. The realistic interactions provided by these technologies can reduce information asymmetry between practice and theory, contributing to faster and more efficient moderation solutions [10]. However, traditional training methods may struggle with learners' separation, which could be addressed by integrating AR and VR in hazard recognition and prevention training [7,11,12].

Furthermore, understanding the variables associated with successful hazard recognition training is critical for both participants and training providers. Evidence on effective training can help identify best practices to reduce hazards and inform the development of strategies to mitigate risks [13]. Several attempts have been made at hazard recognition and prevention, evident across a wide and diverse range of publications employing various approaches [1,13,14]. Several studies have investigated the appropriateness of innovation in hazard recognition, while others have examined components such as sense of presence, engagement, motivation, and situational learning in hazard recognition and prevention [15–17]. Currently, there are narrative reviews on firefighting techniques but no systematic reviews have been published specifically on hazard recognition and prevention [15,18]. Compiling this evidence through a systematic review is essential for identifying recent studies, uncovering any gaps in the literature, and contributing to evidence-based recommendations for training providers in safety and emergency management.

Hazard recognition and prevention is a diverse field that requires focused attention. This research article aims to provide a comprehensive overview of the latest advancements in hazard recognition and prevention using emerging technologies such as augmented and virtual reality, with the objective of assisting future researchers in aligning their work effectively. By keeping the scope of hazard recognition "broad", this article explores the full spectrum of hazard recognition and prevention using AR/VR technologies. The outcomes of this research offer valuable insights into the current state of hazard recognition and prevention research, highlighting the strengths and weaknesses of existing methodologies as well as the associated research limitations. This scoping review explores the literature to determine how AR and VR have been used in training for hazard recognition and prevention. The discussion section supports the key findings of this research, emphasizing the need for collaboration between researchers, practitioners, and developers to address the challenges identified in this report. By understanding the current research gaps and limitations of AR/VR, we can develop more practical hazard recognition skills.

2. Methods

When there is a substantial and distinct body of evidence, scoping reviews are essential for giving an overview of the most recent research and identifying areas that should be subjected to a systematic review with more in-depth analysis [19]. There are various frameworks which have evolved to streamline the process of systematic reviews. PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analysis) is widely acknowledged as the methodological framework for systematic reviews and is advised by many journals [20]. PRISMA provides an evidence-based least set of items that should be consulted and reported, and their resources include a standardized checklist and flow diagram. There are several other entities that do alike job, sharing methodology, providing resources and collating systematic reviews, including the Joanna Briggs Institute (JBI) [21]. This scoping review followed JBI systematic review process [21,22] along with the PRISMASc guidelines. Through this review, a clearer route toward improving training approaches that provide people strong abilities in hazard detection and prevention emerges, eventually enhancing overall safety and resilience in the face of future calamities.

2.1. Stage 1: Identifying the Research Question

The mnemonic Population, Concept and Context (PCC) guides the eligibility criteria and to build the research question [23]. A title and research question were developed by following the PCC strategy which leads to the inclusion criteria. The population consists of general public regardless of their gender and age during this review. The concept was "Use of Augmented and Virtual Reality Technology", and "hazard recognition and prevention" to pursue this scoping review. The following scoping review questions were framed:

- What are the main AR/VR-based technology interventions in hazard recognition and prevention?
- What are the research gaps in the current literature?
- What are the future recommendations to bridge the research gaps?

2.2. Stage 2: Identifying Relevant Studies

Inclusion Criteria

The PCC approach guided the eligibility criteria for this review. The inclusion criteria addressed the following:

- Empirical research methods (Qualitative, Quantitative, and mixed method)
- The following databases were used for the scoping review:
    - ACM Digital Library
    - Google Scholar (First 100 records)
    - IEEE Xplore
    - PsycNet
    - PubMed
    - Scopus
- Papers must address hazard recognition and prevention in disaster management.
- This review included articles which discuss the training and skills development.
- Research in extended or mixed reality were considered if the article discusses about the hazard recognition and prevention.
- Experiments referring to hazard assessment were included.
- Literature must not be older than five years and published in English language.

2.3. Search Strategy

According to the scoping review protocol, a systematic search strategy was applied to find the literature that will be covered in the review [20]. In accordance with PRISMA ScR guidelines, the search strategy must contain a thorough electronic search that utilizes at least one database limited to a specific timeline. To complete the present review, the following databases were chosen as a source of literature on 'Augmented and Virtual

Technology'. (1) Google Scholar (first 100 records), (2) IEEE Xplore, (3) ACM Digital Library, (4) PubMed, (5) Scopus, (6) APA PsycNet. These repositories were chosen in order to create a thorough search and to cover a wide spectrum of relevant literature. Last 5 years' records were included to limit the search for specific time frame. Peer reviewed literature search queries are listed in Appendix A—Table A1. When it is necessary to combine search strings, the Boolean operators 'and' and 'or' were used to direct the search. The Joanna Briggs Institute (JBI) advises using three-step search techniques. Initial keywords were first determined, then the text words in the title and abstract were consulted, together with the index terms used to describe pertinent reviews. The additional terms, such as 'meta-analysis' or 'systematic review', were added to the search terms. Following the construction of database-specific search filters for each bibliographic citation database specified in the protocol, all included reviews' reference lists were searched involving Google Scholar. A final PRISMA flowchart is included to show records of these searches.

2.4. Stage 3: Study Selection

Study selection process was divided into two levels: (1) Title and abstract review, (2) full document review. After the manual databases searches wherever applicable, the first level is to employ the researcher to review the titles and abstracts independently to identify suitable literature for inclusion in the review after deciding the inclusion and exclusion measures, as shown in Table 1. To elaborate further on selection and inclusion criteria at first level, the title of the article was read first, if the title makes use of the term 'hazard', 'risk', 'hazard recognition', 'prevention', along with the term 'augmented reality', or 'virtual reality' is mentioned, then the full abstract was consulted. If the article title, and abstract discuss the use of AR/VR in hazard recognition or prevention, such articles were included in the study otherwise the articles were discarded. Table 1 illustrates the search query used to identify relevant articles. Conflicts were handled by reviewing the findings thoroughly. This eliminated prejudice and resolved disputes. EndNote 20 software was used to export the articles to remove duplicates from the selected articles.

Table 1. Inclusion and exclusion criteria for scoping review.

Criteria	Inclusion	Exclusion
Population	Individuals of all age groups, encompassing both male and female genders.	Robots, animals and birds were excluded.
Concept	Use of Augmented and Virtual Reality Technology in disaster management or hazard recognition and prevention.	Articles were excluded if augmented and/or virtual reality technology was not used in the training.
Context	The training context was investigated.	Studies which were not used in the training context.
Study Design	Peer-reviewed journals were studied where AR and VR related findings were reported.	Reviews, text-book chapters and reports were excluded.
Publication Type	Last 5 years Peer-reviewed articles and conference proceedings.	Studies published before 2017.

Second Level—To establish eligibility requirements, an impartial full text review of research was conducted. All inclusions and exclusions were listed in tabular form as shown in Table 1 with supporting documentation. Following questions help in reviewing:

- Was the article published within the specified time limits?
- Was the article published in English language only?
- Does the examined population match the inclusion criteria?
- Is the study relevant to the review question?
- Are the results measured?

Additionally, 5438 publications were found in the initial search; 5304 were removed after reading the titles and abstracts. We looked at these abstracts in light of inclusion and exclusion criteria. A total of 134 papers underwent full text reviews; 22 studies made it all the way to the end of the charting process, as seen in the PRISMA Flowchart Figure 1 below.

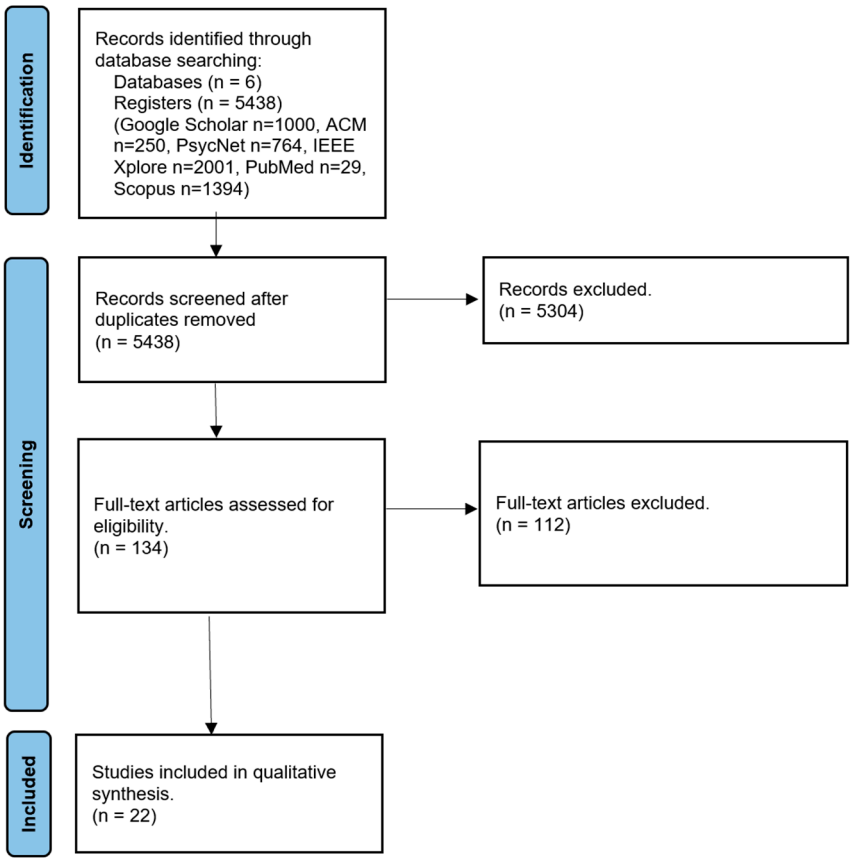

Figure 1. PRISMA flow diagram for scoping review.

2.5. Stage 4: Data Charting

The process of 'charting the data' is used to extract data for scoping reviews. The scoping review included articles' study and participant characteristics were retrieved and tabulated. Information collected from each publication included author and year, study aims/purpose, participants age range, research question/hypothesis, field of study, research methodology/method, HMD/Equipment used, major findings, limitations of the study, and settings. The purpose was to come up with a descriptive summary of the results that addressed the objectives of the scoping review and, ideally, offered solutions to the study's open-ended questions.

2.6. Stage 5: Collating, Summarizing, and Reporting the Results

The scoping review goals was to list and summarize the evidence that is currently available. According to PRISMA extension for scoping review checklist, the findings are presented in a descriptive narrative fashion with a PRISMA flowchart (PRISMA ScR). Organizing and categorizing the studies according to the study techniques are carried out. To report on key ideas and research features, frequent counts are done.

3. Key Findings

3.1. Study Characteristics

A total of 22 articles were meticulously reviewed, as listed in Appendix A, Table A2. Among these, a comprehensive selection process led to the inclusion of articles from a

diverse range of fields. Notably, five articles were drawn from the realm of Civil Engineering and Construction Sites, shedding light on hazard recognition and prevention within this critical sector. The literature review includes articles from various sectors, including fire and emergency departments, healthcare and medical sectors, driving simulators, coal mining sports, agriculture, and falls prevention in older adults. These diverse fields provide a balanced view of hazard identification and mitigation in various realistic settings. The aim is to provide a good cross-section view and incorporate various sectors and scenarios, thereby expanding the understanding and study of hazard identification and mitigation in various realistic settings.

The exploration of augmented and virtual reality (AR/VR) interventions in enterprise hazard identification demonstrated unique trends with regard to the share of contributions from the field. Notably, civil engineering and the construction industry demonstrated significant use of AR/VR technology, primarily for risk assessment exercises. This sector also showed considerable interest in applying VR/AR technology to enhance hazard identification and management. The Fire and Emergency department emerged as a major user of AR and VR, particularly for training employees to handle emergencies. Ranking third, the healthcare and medical sectors highlighted the potential of AR/VR for improving hazard assessment in medical settings. Additionally, these technologies have been applied in fields such as sports, driving simulations, agriculture, and fall prevention for older adults. As highlighted in this paper, AR/VR interventions have proven versatile enough to adapt to difference scenarios across various fields, changing approaches to hazard assessment while promoting safer, better-informed decisions. Figure 2 below shows the frequency of research submissions by year and geographic location.

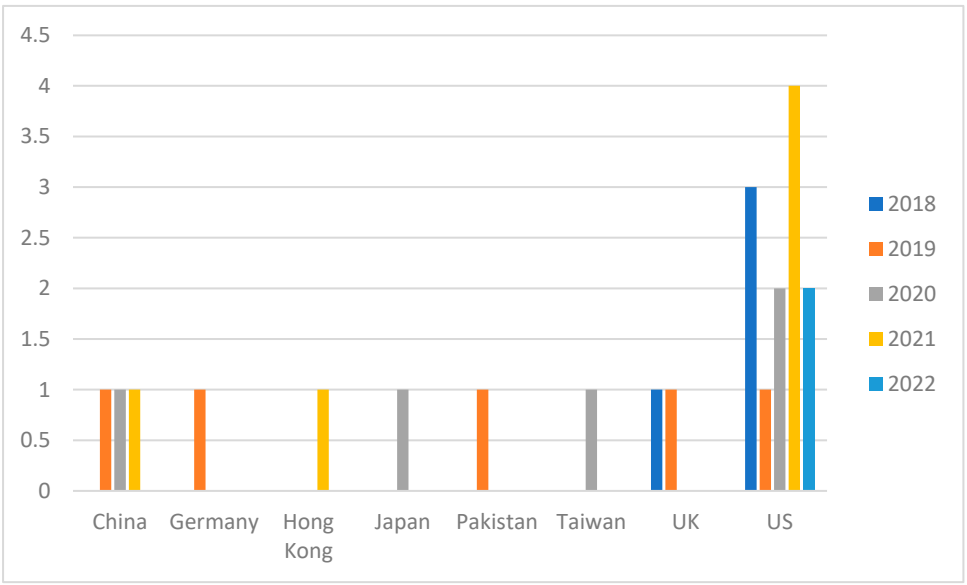

Figure 2. Yearly Geographical Research Contribution.

Moreover, analysing the temporal distribution of publications revealed that the years from 2019 to 2021 saw the most significant contributions in hazard recognition and prevention research. Geographical patterns of research contributions shed light on the regions actively engaged in hazard recognition and prevention research. Notably, the United States, China, and the United Kingdom emerged as significant contributors in this field. These countries displayed a strong commitment to research in this domain, which aligns with their prominence in research and development in various sectors.

3.2. Participants Recruitment Samples

Out of the 22 articles reviewed, 9 articles focused on recruiting Civil Engineers as their study participants. This indicates a significant emphasis on this professional group within the reviewed literature.

The study focuses on the application of Augmented Reality (AR/VR) interventions in various occupational fields, including students, medical staff, senior citizens, and athletes. Three articles, including those by articles [21,24–26], are exclusively about students, reflecting the research community's interests in academic populations. Two articles [27,28], focus on medical staff, indicating a healthcare perspective. The scoping review is broad, covering participants from various groups and genders. However, two articles did not clearly describe participants, raising questions about missing data in reporting results.

3.3. Goals and Applications of AR and VR

The analysis of the twenty-two reviewed studies exposed important features of the various ways in which AR and VR are employed. These articles contribute to increasing the knowledge database in the field, and the work they do can be grouped into several topics. Out of 17 papers, augmented reality and virtual reality have benefited authors in acquiring new content knowledge [4,29–31] as shown in Figure 3, explaining why they have been used as instructional tools. These technologies have been pointed out as crucial by 13 publications for Workplace Health and Safety [14,32]. Moreover, 5 papers have explored the cognitive development [7,31,33] that the AR/VR can provide. Two papers were aimed at increasing general effectiveness [34,35], assessing immersion aspects [28,36] of AR/VR and comparing costs with non-technological solutions [24,29,37].

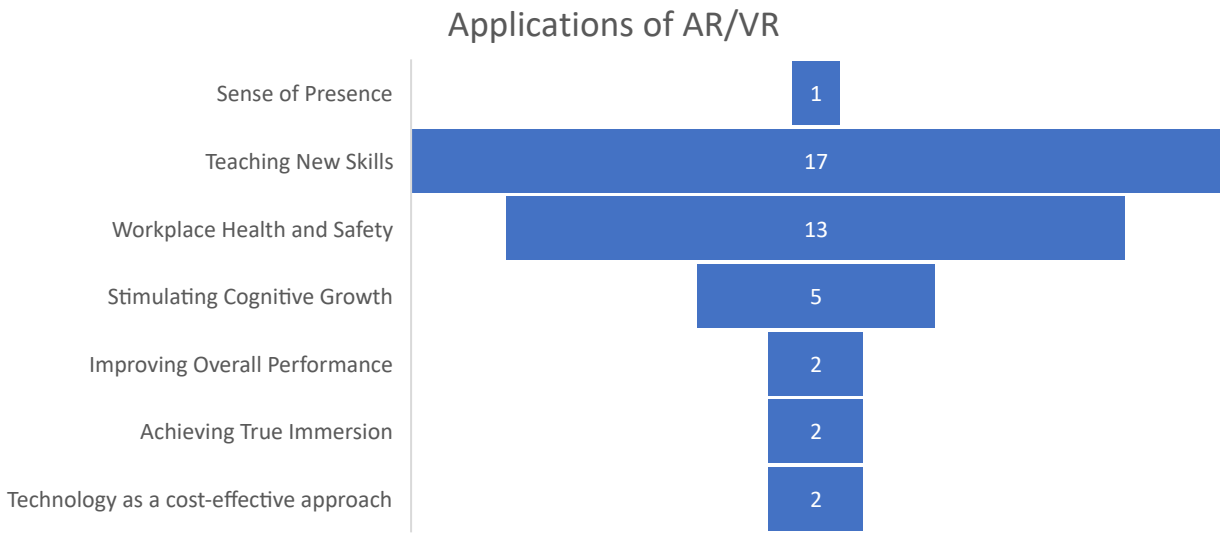

Figure 3. Applications of AR/VR.

Furthermore, one paper significantly contributes to understanding presence in AR/VR contexts, highlighting the diverse nature of AR/VR technology and its broad applicability across various fields, underscoring the transformative potential of these technologies in various domains. From skill acquisition and performance enhancement to improved safety practices and cognitive development, the study illuminates the multifaceted positive impacts of integrating AR/VR interventions into diverse contexts.

3.4. Major Limitations

The scoping review uncovered several noteworthy limitations that warrant consideration when interpreting the findings. These include:

3.4.1. Limited or Non-Diverse Sample Sizes

The review unveiled some papers having low sample sizes or inadequate diversity of the participants. Observing the 22 articles, 9 of them have mentioned that the study was unable to recruit people with required characteristics, number, or the sample size utilized either male or female but not both simultaneously. The authors have also pointed out that occasionally participants included were not necessarily obtained from the field of interest. This may bring some bias when generalizing the results to other populations in the community and/or, countries.

3.4.2. Absence of Real-World Scenarios or Contextual Learning

The study identified a challenge in enhancing hazard identification and mitigation using AR/VR in game environments, with 8 out of 22 articles not considering contextual learning. Additionally, the lack of real-life case scenarios was noted, which could affect the generalization of the findings to real-life situations [14,15,28,34,36,38–40]. This highlights the need for more comprehensive and realistic scenarios in game environments.

3.4.3. Inadequate Game Mechanics and Validation

Out of them, four studies were found to be having inadequate game mechanics [23,35,38,41]. Additionally, many use cases lacked proper testing and validation, potentially compromising the reliability and effectiveness of the interventions.

3.4.4. Lack of Dynamic Behaviour in Games

Lack of dynamic behaviours within game simulations was considered as a limitation in three papers [3,30,40]. Lack of dynamic elements may cause the effective and realistic training interventions to be more of a simulation than actual.

3.4.5. Need for Inclusion of Expert Insights

Five researchers highlighted the need for further studies of various types, for instance, based on the analysis of previous accidents and/or interviews with specialists [11,29,32,42,43]. This would help in adding more depth and understanding of the feasibility of the interventions in real life application.

3.4.6. Technology Issues and Sensor Problems

Some of the strategies' constraints were pinpointed concerning the technology to be employed in the proposed solutions. Two articles discussed some of the issues with the sensors used that indicated that depending on the situation, the sensors may affect the effectiveness of the interventions for corresponding scenarios [21,44].

3.4.7. Uncertainty Regarding Long-Term Impact

Scholars identified a limitation in game-based training, as the results were not conclusive on the long-term implications, leading to two articles [11,39]. This lack of clarity could affect the holism of such interventions.

3.4.8. Cost Comparison with Traditional Training

Research on the cost of game-based training is essential to determine if it is cheaper or more expensive than traditional training [4,29,37]. This assessment will provide insights into the potential of AR/VR-integrated interventions and their real-world possibilities. However, limitations should be considered in future studies to avoid them and improve training interventions in AR/VR environments. Understanding these limitations can help avoid potential drawbacks and enhance the effectiveness of AR/VR training.

3.5. Prominent Research Questions or Hypotheses

The use of Augmented Reality (AR) and Virtual Reality (VR) in hazard recognition and prevention comprises a rich tapestry of research aims, as seen by our extensive evaluation

of 22 selected papers. Three publications theorized and focused their research on increasing the experience of immersion in AR/VR settings [4,7,28] highlighting the importance of immersion. Four publications have focused on the immersive characteristics of virtual simulations and their possible impact on attention [36,38,41,45] laying the way for lively debate. Furthermore, three publications attempted to give useful comparative assessments, pitting traditional training techniques against cutting-edge AR/VR training methodologies [4,33,46] so providing crucial insights into these technologies' revolutionary potential. A notable subgroup of six publications conducted variable comparisons, adding to our understanding of the intricacies of AR/VR adoption [11,24,31,42,46,47]. Issue with technology adoption is an umbrella term used in AR/VR that refers to in-adequate headmounted display sizes, feelings of fatigue due to excessive use, motion-sickness and safety issues. Discussion of these terms are beyond the scope of this article. However, AR/VR genuinely shines in the arena of practical experience and safety measures [3,4,14,23,29,31,34,36,44,45,47–49], with a sizable 13 papers making major contributions in this sector as depicted in Figure 4. These findings highlight the diverse nature of AR/VR research and the critical role it plays across a wide range of applications and goals.

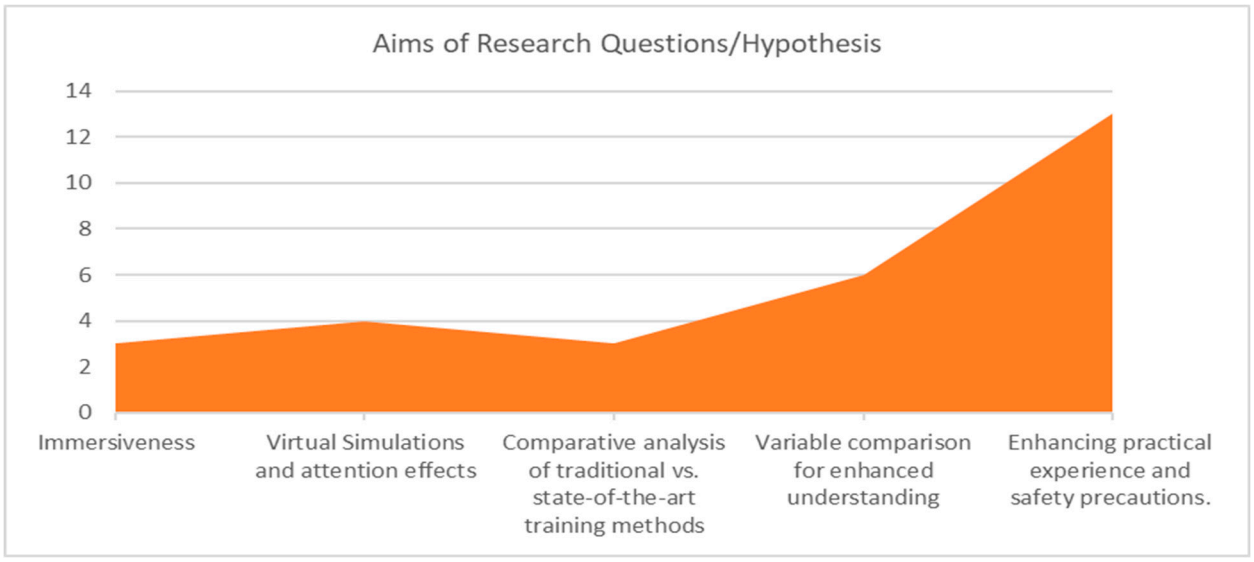

Figure 4. Research Questions or hypothesis.

In summation, the findings highlight the interconnected and multidimensional nature of research questions and hypotheses in selected articles, aiming to expand knowledge on AR/VR interventions for hazard detection and mitigation. By studying these complex dimensions, researchers aim to enhance safety interventions, increase cognitive involvement, and optimize training approaches for a safer and more knowledgeable environment.

3.6. HMD or Equipment Used

AR and VR in the hazard identification and risk mitigation field, specifically while using the tools and technologies emphasizes their function as critical factors for determining the results. The following is the list of the HMD/equipment used in the reviewed articles as shown in the Figure 5 below. Out of the 22 articles reviewed, seven articles adopted HMD, including OnePlus, HTC Vive, and Oculus Quest/Rift, and other immersive tools [28,29,31,32,35,37,38]. All these devices acting as a window to the AR/VR worlds enable deep interactions. Overall, five research papers have focused on the issue of integrating more sensors, which only makes the sense of presence and performance even better while at the same time supplying new skills. These sensors include gyroscopes, Garmin Vivo smart devices, wristbands, accelerometers, and emotive sensors [28,36,42,45,47]. Four articles have focused on the use of 3D Goggles, including Tobii as a brand [3,24,33,37].

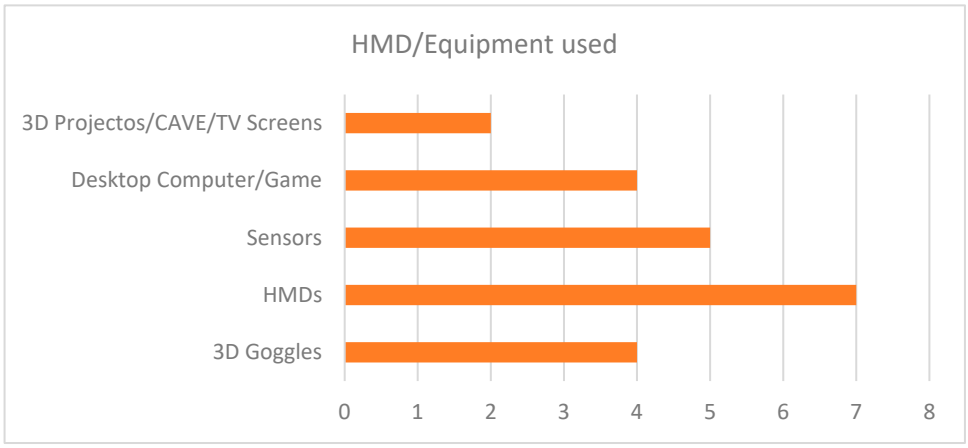

Figure 5. HMD or Equipment Used.

Moreover, an equivalent quantity of articles has used conventional yet efficient approaches; utilizing either Desktop computers or laptops as the fundamental hardware in their trials [11,34,44,48]. However, in terms of exhibition, only two articles have gone a step further and used 3D Projector screens, TV screens or even design CAVE environment to discover the potentiality of AR/VR technology [24,37,41]. All these choices in the hardware are in harmony with the diversification and creativity in the technological space of the AR/VR research.

4. Discussion and Conclusions

4.1. Discussion

The scoping review of 22 articles on hazard identification and risk reduction provides valuable insights for future researchers. Key patterns and trends are identified, including the importance of Google Scholar [29] and PubMed in hazard identification and risk avoidance [50]. These databases use technology related to extended reality for knowledge sharing. The review also highlights the enhancement of research work in the past three years, with active engagement in hazard identification and the use of AR/VR for risk avoidance [5]. This trend indicates a positive trend in future developments in this field, with optimism for significant progress in the coming years. On a global scale, the United States of America [10] the UK [14], and China [26] significantly contributed to the advancement of knowledge on hazards and prevention using gamification. The term gamification refers to game-based learning and it covers serious games, educational games to develop cognitive skills etc. They offer diverse perspectives on this crucial subject. The Civil Engineering and Construction Sites sector has seen a greater focus on identifying hazards and risk control measures [51]. The fire and emergency domain and medical sector have also seen the application of AR/VR in safety-oriented sectors [14,52], highlighting the importance of these technologies in various sectors.

The scoping review revealed key findings on the effectiveness of AR/VR interventions in teaching new skills, health and safety [26,53] true reality [54], cognitive skills [2] and organizational performance [42]. These findings affirm the efficiencies of AR/VR interventions, demonstrating their potential to revolutionize training practices and improve safety, and provide evidence for their potential to improve overall organizational performance. The scoping review of 22 articles revealed a lack of contextual knowledge and real events in the use of AR/VR in gamification. Despite being effective tools for simulating dangerous scenarios, there is a need for better integration of contextual learning into risk assessment and risk avoidance planning [55,56]. This is a missed opportunity for real-life scenarios training. The small sample size raises questions about the generalizability of the results and calls for more comprehensive sampling techniques [16,57]. Despite the stimulating nature of the gamified approach, there are disadvantages, such as the dynamic restriction of game behaviours in hazard recognition and prevention programs. However, the strong

dynamics of interactions within the virtual world enhance the realism and effectiveness of training scenarios [58,59].

Further research should consider more comprehensive sampling techniques to increase confidence in the results' generalizability [60]. One more factor requiring focus is external validation [32,61], because the input from experts can enhance the effectiveness of the gamification technique [13]. Moreover, the incorporation of sensors into the process of gamification is important [22] because it may provide actual information and evaluation, thus enhancing the learning process [22,62]. Finally, one of the major weaknesses it is the absence of sufficient variation in gamification activities conducted through augmented reality and/or virtual reality [63]. The importance lies in utilizing outcomes in diverse scenarios for hazard identification, avoiding limited context [27].

Additionally, the identified research gaps and ideas for future work include discovering more fields where extended reality could be applied, such as fire hazard identification in dwelling areas and hazard identification in flight operations [38]. One limitation pointed out is the lack of context, that is, no real-life applications featured in some of the research studies. Further work, emphasis should be made on the improvement of contextual learning through to focus on, a more immersive environment as well as presence in the virtual environment [55]. Based on the variation in the participant sample sizes, the future research should develop a set of rules and regulations in sampling techniques in the gamified learning environment [52,64]. This would mean actualizing more generalizable results at net level [63,65].

In order to increase the external construct validity of future research, the authors suggest that the industry specialists should be involved at all stages of user validation/testing [66]. The proposed extended reality interventions could have improved the quality and relevance of the current interventions, particularly in investigating the effects on instructional outcomes, particularly lasting knowledge and skills gains [67]. Evaluating the extended impact of training is crucial to determine the duration of learning results. Future research should compare the costs of using AR/VR training environments to other types of training to ensure comprehensive understanding [68].

Actualizing associated variables, researchers can provide an understanding into the economic efficiency and benefits of extended-reality training. Another good word of the advice is the effectiveness of surveys as the primary tool to gather requirements. To contribute towards the solution of the problem, researchers can formulate adequate study questions that align with the existing requirements and challenges in disaster management through involving stakeholders, practitioners, and future users as suggested by [69]. Researchers are stressing on making the semantics of interventions more efficient, feasible, and realistic. They are adopting other top-notch technologies such as those are Oculus Quest Pro, HoloLens and Apple Vision to improve the touch sensation allow to enhance the graphic processing and create better and more entertaining AR/VR memorable [70,71]. Dynamic graphics processing and user comfort are key factors influencing client engagement and safety instruction efficiency. Designers and developers should maintain a user-centred approach, focusing on individual preferences and ergonomic requirements, to ensure the successful implementation of these technologies [49,72]. This will increase user engagement and improve safety results in a variety of industries [37,73].

Furthermore, the analysis of the publication year indicated that the identification and risk prevention has been active and most productive in the years 2019, 2020 and 2021 as depicted in Figure 2. This indicates that there was enhanced focus on this area at this period suggesting that more attention was being paid to the area. Research may have increased in these years due to an increased focus on safety and risk factors and the quest for new solutions to risks [74,75]. By addressing these gaps and exploring the outlined directions, future research in the field of extended reality for hazard recognition and prevention can pave the way for more effective and impactful training approaches, fostering safer and more informed decision-making across diverse domains.

Initially, we started our search in a broad range to cover each and every aspect of hazard recognition and prevention using augmented and virtual reality. After completing the scoping review survey, we managed to narrow down our research findings to fewer areas where hazard recognition and prevention were applied. This approach helped us to identify the current use of hazard recognition and prevention using AR/VR across diverse industries and domains. Our findings offer valuable insights for future researchers to enhance their research and follow the best practices. A notable trend observed is the widespread adoption of technology in the civil engineering and construction sites as they possess lots of challenges in hazard recognition and prevention. By incorporating augmented and virtual reality technology these industries have significantly improved their hazard recognition and prevention capabilities. Healthcare and medical sectors follow closely behind, recognizing the potential of technology-driven hazard recognition and prevention trainings. Other establishments including driving simulators, coal mining, sports, agriculture and falls prevention in older adults had helped identifying and mitigating hazards. By examining these various fields, we can gain a deeper understanding of identifying, assessing and mitigating hazards and overcoming the research gaps identified in this scoping review.

4.2. Conclusions

The scoping review of 22 articles highlights the dynamic and evolving field of the hazard identification and mitigation through the use of augmented and virtual reality (AR/VR) technologies. This review has provided informative and insightful perspectives on the integration of AR/VR for enhancing safety measures and training across a range of sectors. It underscores the prominent role of AR/VR in supporting skill development, enhancing safety awareness, and improving performance. Applications of AR/VR have been implemented in diverse domains such as civil engineering, construction, fire and emergency services, and healthcare. These contributions reflect coordinated global efforts to improve hazard identification and coping strategies.

This review also identifies several limitations in AR/VR applications, including insufficient research into game mechanics testing, contextual learning, and participant recruitment. Despite their apparent ease of integration, AR/VR technologies still face challenges that need to be addressed to create more effective interventions. Addressing these limitations will help pave the way for broader application of AR/VR across different fields, enhancement of contextual learning experiences, and long-term assessment of knowledge retention.

Overall, this scoping review serves as a guiding reference for future research, providing valuable insights for researchers, practitioners, and stakeholders invested in safety management. As AR/VR technology continues to evolve, this comprehensive analysis will undoubtedly contribute to the development of effective hazard recognition and prevention strategies, ultimately fostering safer environments and more informed decision-making.

This study was conducted in early 2023. The results may vary if the same search string is used beyond this period.

Author Contributions: T.F. led the conceptualization of the research question and conducted the literature search and literature review. A.A.M. developed the methodology and suggested the JBI protocol for scoping review, M.T.K.T. assisted in data collection instruments. M.T.K.T. and A.A.M. performed the data validation. K.Y.S. reviewed the work and gave his insights in improving the writing style. All authors have read and agreed to the published version of the manuscript.

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Data Availability Statement: Scoping review downloaded articles and excel sheet data can be shared on request. Articles reviewed during the scoping review are added in the Appendix A.

Conflicts of Interest: The authors declare no conflicts of interest.

Appendix A

Table A1. Search Queries.

Database	Search Query
Scopus	((TITLE-ABS-KEY(augmented AND reality) OR TITLE-ABS-KEY(virtual AND reality) AND TITLE-ABS-KEY(hazard AND recognition) OR TITLE-ABS-KEY(prevention)) AND PUBYEAR > 2016 AND PUBYEAR > 2016)
IEEE Xplore	(“All Metadata:Augmented Reality) OR (“All Metadata”:Virtual Reality) AND (“All Metadata”:Hazard Recognition) OR (“All Metadata”:Prevention) Filters Applied: Conferences, Journals, Early Access Articles 2017–2023
Google Scholar	([Augmented Reality] OR [Virtual Reality]) and ([Hazard recognition] OR [Prevention]) Custom Range. . . 2017–2023
PubMed	((“augmented reality”[MeSH Terms] OR (“augmented”[All Fields] AND “reality”[All Fields]) OR “augmented reality”[All Fields] OR (“virtual reality”[MeSH Terms] OR (“virtual”[All Fields] AND “reality”[All Fields]) OR “virtual reality”[All Fields])) AND ((((“hazard”[All Fields] OR “hazard s”[All Fields] OR “hazardous”[All Fields] OR “hazardously”[All Fields] OR “hazardousness”[All Fields] OR “hazards”[All Fields]) AND (“recognition, psychology”[MeSH Terms] OR (“recognition”[All Fields] AND “psychology”[All Fields]) OR “psychology recognition”[All Fields] OR “recognition”[All Fields] OR “recognitions”[All Fields])) OR (“prevent”[All Fields] OR “preventability”[All Fields] OR “preventable”[All Fields] OR “preventative”[All Fields] OR “preventatively”[All Fields] OR “preventatives”[All Fields] OR “prevented”[All Fields] OR “preventing”[All Fields] OR “prevention and control”[MeSH Subheading] OR (“prevention”[All Fields] AND “control”[All Fields]) OR “prevention and control”[All Fields] OR “prevention”[All Fields] OR “prevention s”[All Fields] OR “preventions”[All Fields] OR “preventive”[All Fields] OR “preventively”[All Fields] OR “preventives”[All Fields] OR “prevents”[All Fields]))) AND ((y_5[Filter]) AND (english[Filter]))
ACM Digital Library	ACM DL: Query Name, Search Run Date, Search Result Count, Query Syntax ACM Search String,2022-12-29 at 04:24:15 PST,12,857, “query”: {Title:(([Augmented Reality] OR [Virtual Reality]) and ([Hazard recognition] OR [Prevention]))} “filter”: {E-Publication Date: (01/01/2017 TO 1/1/2023)}, {ACM Content: DL}
APA PsycNet	Title: Augmented Reality OR Title: Virtual Reality AND Title: Hazard Recognition OR Title: Prevention AND Year: 2017 To 2023

Table A2. Data Extraction.

Author, Date/Settings	Aim of the Study/Participant Age Range	Research Questions/ Hypotheses	Field of Study/ Equipment (HMD) Used	Research Methodology/Method	Major Findings	Limitations of the Study
[65] / Baylor University Medical Center Dallas Texas (BUMC), USA.	The aim of this study is to evaluate the impact of an immersive virtual reality (VR)-based OR fire training simulation system in combination with FUSE didactics. / 20 (9M, 11F) Age (18+)	Does training in an immersive VR environment improves performance as compared to FUSE didactic material?	Operating Room Fire Management / Oculus Rift HMD	Wilcoxon Signed-Rank test with pre/post-test scores Mann–Whitney U test was used to assess the differences between the groups. Cronbach's Alpha and Intraclass Correlation	Interactive VR-based hands-on training was found to be a relatively inexpensive and effective mode for teaching OR fire prevention and management scenarios.	The testing of the system was done on a single scenario of patient on fire. Even the single user simulation environment, having the ability to simulate airway fire would be a valuable addition. In the future, training multi-user through teams would be more effective in OR fire prevention and control.
[64] / Ulster University, Northern Ireland, UK	Proposed a system which make use of VR technology to simulate driving for the purpose of hazard recognition evaluation, incorporating the collection of eye-tracking data and its contextual analysis. / (Not specified) Age (18+)	Acquiring the data necessary to analyze a subject's attention (e.g., head and eye gaze trajectories) and suggesting a methodology utilizing supervised machine learning to evaluate this dataset and forecast proficiency in hazard identification.	Driving Simulator / HTC Vive/FOVE Eye Tracking	Eye-movement data: Cumulative fixation time and cluster analysis	Tracking of eyes in simulated VR environment enables to assess the situations pertaining to challenging eye tracking situations in real-word contexts.	The autonomous vehicles movement should not depend on the frame rate and it requires the dynamic temporal data.
[9] / University of Florida, USA	Traditional passive learning skills development methodologies are no longer relevant to hazard identification. Virtual Reality as an alternate source can provide immersive environment to engage the learners, and improve knowledge retention as compared the conventional techniques. / 30 (27M, 3F) Age (19–40)	Environment prefabs or models developed in three dimensions permit users to provide realistic experience in a proper rendered scene. To cater the needs of realism, 360-degree screens have been utilized in the recent literature to make the environment immersive for construction safety trainings.	Construction Sites / Insta 360 Camera, Desktop Computers	Carter and Smith developed HII (Hazard identification index) and scaling to assess hazard identification. In order to reflect the learners attainment, a grading system automates the potential responses which corresponds to three scenarios: 1. Correct Identification or rejection (CIR) 2. Incorrect identification (II) 3. Missed Identification (MI)	An interactive, immersive and engaging environment was produced using the 360-degree panoramas for construction safety trainings. To achieve this, OSHA and SHG training resources were consulted and incorporated in the proposed learning environment.	These findings restricts the generalization of results due to insufficient sample size. Furthermore, the outcomes of this research work pertain to selected population i.e., students' majoring in civil engineering. Alternate groups such as actual construction workers, managers and professionals may provide varying outcomes. The scope of this study is also limited to hazard identification with limited scenarios.
[30] / University of Massachusetts, USA	A driver simulator used to make advance alerts to indicate young drivers about the upcoming hazard in this research work. / 48 (24M, 24F) Age (18–25)	The research objectives were divided into three stages: 1. Analyze the impact of HUD alerts on young drivers 2. Identify the warning time onset delivers the most benefits in a scenario where young drivers are completely focused on the road ahead. 3. Assess the distracting effects of the HUD. The research makes the contribution of suggesting 4-s signal before to a latent threat makes the adolescent drivers to effectively foresee the hazard.	Civil and Environmental Engineering, Driving Simulator / Driving Simulator, Head-mounted monocular eye tracking system and overhead projectors.	Three variables were used which shows their dependencies to each other: 1. assessment of drivers' hazard identification abilities. 2. Assessment of driver's response with respect to hazards, and 3. measuring the distracting potential. Participants responses were consolidated, and *t*-tests were employed.	This work examined the impact of HUD alerts at various levels of adolescent drivers with respect to hazard recognition and response. Pedestrian and vehicles was represented as hazards aiming to enhance hazard recognition and mitigation skills while ensuring the attention abilities of player.	A few questions left unaddressed in this study such as The heightened attention to the concealed risk was prominently due to the result of drivers' gaze being drawn to the alert. This novelty leads to adopt a more useful driving behaviour in young drivers.

Table A2. *Cont.*

Author, Date/Settings	Aim of the Study/Participant Age Range	Research Questions/ Hypotheses	Field of Study/ Equipment (HMD) Used	Research Methodology/Method	Major Findings	Limitations of the Study
[45] / UET Taxilla, Punjab, Pakistan	The article present sensor-based wearable fall monitoring device that facilitates fall detection, identification of falling patterns, and fall incidents activities. / 38 (Not Specified) Age (Not Specified)	Machine learning algorithm was used in adults for real-time fall detection.	Healthcare / Camera, Gyroscope Sensor, Accelerometer Sensor	The real-time fall monitoring system continually collects sensor data in ten-second increments utilizing a non-overlapping frame. The obtained data is subsequently analyzed to determine the incidence of a fall. Upon detection of a fall, the system subsequently analyzes the data to classify the falling action using supervised machine learning. KNN, SVM, and RF machine learning models were employed to assess model performance.	Identifying actions that contribute to falls, such as sliding while walking, tripping when running, and falling while seated, constitutes the primary fall-related activities.	Additional sample data is necessary, and fall prevention must be included for improved outcomes. Additional sensing modalities, like cameras and pressure sensors, can be integrated with motion sensors to enhance the accuracy of fall detection and recognition.
[34] / Brunel University London, UK	A comprehensive 3D exploration game designed to enhance awareness of environmental fall dangers (extrinsic) present within the house to assess the comprehensive usability of the game from the standpoint of older adults. This investigates older persons' perspectives of utilizing Falls Sensei. / 15 (6M, 9F) Age (50–80)	The research uses serious games for fall prevention in older adults and presents gaming in developing fall prevention skills.	Falls prevention in older adults / Desktop Computer	The UTAUT (Unified Theory of Acceptance and Use of Technology) research methodology was employed which shows that 70% of user population accepted the new technology based on Performance Expectancy, Effort Expectancy and Social Influence.	The study outcome indicate that educational games should be regarded as a supplementary resource for teaching adults on how to prevent falls in their habitat.	Future research should encompass a larger-scale randomized controlled trial to ascertain the degree to which engaging in serious games like Falls Sensei facilitates learning about fall hazards in comparison to the efficacy of conventional fall education methods, such as informational leaflets. Further revisions of design, development, and user testing are necessary.

Table A2. *Cont.*

Author, Date/Settings	Aim of the Study/Participant Age Range	Research Questions/ Hypotheses	Field of Study/ Equipment (HMD) Used	Research Methodology/Method	Major Findings	Limitations of the Study
[24] / Department of Psychology, University of Bamberg, Germany	The study evaluated the efficacy of immersive VR-based safety training compared to safety training delivered by PowerPoint (PPT). / 68 (43M, 25F) Age (±18)	The study examines three personality traits. 1. locus of control 2. conscientiousness 3. risk attitude Hypotheses taken from the research article: *"H1. On the basis of previous research, expect that the participants in the immersive VR condition would experience a higher sense of presence. H2. Assuming that VR-based safety training would have a stronger impact than safety training offered* via *a PPT presentation on risk judgments. H3. Expecting that the participants to recall more safety-relevant information and to detect more hazards when facing a real machine after experiencing safety training in VR. H4. Expecting that in the immersive VR condition, risk-related decisions would be more strongly affected by participants' recall of safety knowledge and identified hazards than in the PPT condition, reflecting a higher degree of knowledge integration in the immersive VR condition".*	Department of Psychology / CAVE Environment, 3D Glasses	Following data analysis approach were followed: Descriptive statistics, Chronback's alpha and T-Tests.	According to this study, level of immersion was higher in VR environment; however, there was no big difference found in risk identification using PowerPoint vs. VR. The retention of safety knowledge was inversely correlated with risk-taking health and safety domains.	The data was insufficient to generalize the results in this study. Variations in risk perception are more prominent in VR as compared to PowerPoint slides. Knowledge retention in both mediums did not show significant variations.

Table A2. *Cont.*

Author, Date/Settings	Aim of the Study/Participant Age Range	Research Questions/ Hypotheses	Field of Study/ Equipment (HMD) Used	Research Methodology/Method	Major Findings	Limitations of the Study
[49] / Department of Construction Management, Tsinghua University, Beijing, China	This article seeks to investigate visual search techniques via eye-tracking scan patterns as a surrogate for cognitive representations in building safety inspections. / 47 (34M, 13F) Age (18+)	Scanning path analysis in hazard recognition using visual search strategies.	Department of Civil Engineering / Eye-tracker Tobii Pro Glasses 2	Hierarchical clustering of fixation sequence, Transition probability matrix and box plots were used to analyse the data.	The findings of this study extend knowledge of the visual search stage of hazard recognition in dynamic real-world construction scenes. Overall, the study contributes to understanding of eye movement behaviours during safety inspections, elucidating the cognitive mechanisms of hazard recognition at construction sites.	Certain limitations of the study need to be considered. First, the hazard identification rate was quite low, as only two hazards out of ten received fixations from half of the participants, suggesting perhaps that the participants might not have been the most suitable to this experiment design. Future studies should try to use more appropriate target groups. Second, more hazard scenarios and sample data are required to confirm the results and further examine the relationship between hazard type and hazard searching strategy. Third, the generation process of posterior areas of interests (AOIs) in future studies should be more precise to amount for the correlation between fixations by the same participant. Furthermore, the method for generalizing common scan patterns can be improved, with more quantitative methods applied to arrive at a common scan path or scan band that could more clearly demonstrate, how exactly high-performance inspectors search for a hazard. Finally, further studies are needed to test and verify the practical implications of these results.

Table A2. *Cont.*

Author, Date/Settings	Aim of the Study/Participant Age Range	Research Questions/ Hypotheses	Field of Study/ Equipment (HMD) Used	Research Methodology/Method	Major Findings	Limitations of the Study
[17] / University of Mining and Technology, China	Improving efficiency and quality of practical teaching for underground grouting fire prevention and extinguishment using Virtual Simulations. / (Not Specified) Age (18+)	What is the effectiveness of a virtual simulation teaching system for grouting fire prevention and extinguishment, and how can such a system be designed and applied in educational settings?	Coal Mining / VR Helmet, 3D Stereo Display	Study uses Design and development which involves software development, user interface designing, and creation of virtual scenarios and models. The researchers have conducted experiments to evaluate the effectiveness of the virtual simulation teaching system in improving learning outcomes. The study has involved the analysis of quantitative data (e.g., test scores, survey responses) and qualitative data (e.g., feedback from users) to assess the effectiveness of the virtual simulation teaching system.	Effectiveness of VR Simulations in Practical Knowledge and Skills.	Not specified
[41] / Virginia Tech University, Virginia USA	This empirical study developed an immersive MR (Mixed Reality) scenarios to facilitate risk free interaction for people while observing varying level of perception of protection among individuals. / 33 (28M, 5F) Age (21–25 years)	The study hypothesis are shared below with four hypothesis to evaluate sense of presence and the suitability of MR platform for studying workers risk taking behaviours. *"H1: The developed MR environment with passive haptics strengthens the workers' self -report senses of Presence and senses of working on the roof of a two-story building. H2: In the MR environment, workers' reactionary physiological signals change under different experimental conditions* (i.e., *adding/removing tactile augmentation of safety interventions) in accordance with Risk Compensation Theory, and provide objective measures of Presence.*	Construction-site workers / 3D Goggles, Head-tracking sensors, ankle location-tracker bracelet and Garmin Vivosmart HR+ Wristband	The study uses the following BFI test Big Five Personality Trait Inventory). Participants were asked to use 3D Goggles along with sensors.	Concerning the perception of height, the findings from the Presence question indicated that 88% of participants considered the MR simulation to be realistic. Participants indicated that various elements integrated into the MR enhanced their perception of being atop a two-story structure: the auditory and wind effects; the lifelike virtual depiction of a suburban setting; and notably, the incline, which compromised their stability and prompted caution against falling.	The sample size constrains the generalizability of the current study; thus, further research should repeat this study with a larger participant pool to mitigate this restriction. Secondly, the current investigation was conducted in a controlled environment, with oversight of the MR system and regulation of the perspective according to the individual's head position. Future research is advised to investigate the impact of peer presence on the sensation of telepresence or to enable many users to collaboratively manipulate the system and alter the viewpoint. The present study focused exclusively on two personality qualities, analyzing each independently to assess their influence on Presence measurements.

Table A2. *Cont.*

Author, Date/Settings	Aim of the Study/Participant Age Range	Research Questions/ Hypotheses	Field of Study/ Equipment (HMD) Used	Research Methodology/Method	Major Findings	Limitations of the Study
		H3: With heightened Presence, workers adjust their risk-taking behaviour under different experimental conditions in accordance with Risk Compensation Theory. *H4: With heightened Presence, workers' productivity changes under different experimental conditions in accordance with Risk Compensation Theory".*				Future research should examine the potential interplay between personality traits and demographic variables that may influence an individual's feeling of presence.
[4] / Ministry of Science and Technology, Taiwan	The purpose of fire safety equipment (FSE) inspection and maintenance is to ensure that the equipment is in good working condition during emergencies, so that fire damage could be kept to a minimum. / 9 (Not Specified) Age (20+)	How can Building Information Modeling (BIM) and augmented reality be effectively integrated to improve the process of inspecting and maintaining fire safety equipment?	Fire Safety Equipment Inspection and Maintenance / Apple IOS tablet	Literature was consulted for fire safety equipment inspection, interviews were conducted, System was designed for BIM-Augmented Reality Fire Safety Equipment Inspection, participants were evaluated based on the proposed system and results were validated using descriptive statistics such as mean, median, standard deviation, Levene's test and *t*-test for equality of means were performed in the end.	The findings of this research are summarized as follows: 1. Based on expert interviews and literature reviews, it was found that FSE inspections and maintenance are different from ordinary FMM operations. 2. A systematic analytical inspection system could be used to understand the information relationships of the inspection and maintenance system. 3. This study created the AR inspection points in the BIM model and applied the iBeacon technology for data transmission. 4. The system developed in this work could effectively replace the use of 2D paper files in equipment inspections.	The framework constructed in this study is capable of analyzing information requirements and application models, it is found that inexperienced analyst may not be able to correctly identify the information requirements of certain operations. Therefore, expert experience is extremely important for the analysis of the proposed system.

Table A2. *Cont.*

Author, Date/Settings	Aim of the Study/Participant Age Range	Research Questions/ Hypotheses	Field of Study/ Equipment (HMD) Used	Research Methodology/Method	Major Findings	Limitations of the Study
[39] / University of Colorado Boulder, USA	The aim of the article is to investigate and understand the impact of human emotions on construction-related tasks such as hazard identification, risk assessment, and safety decision-making. The article likely seeks to explore how the integration of augmented virtual reality (AVR) can provide insights into the cognitive and emotional processes that influence individuals' abilities to recognize and respond to potential hazards in construction environments. / 73 (Not Specified) Age (18+)	The purpose of the present study is to explore the literature within construction safety, applied psychology, and decision science to build a theoretical model of the relationships among constructionhazard identification, risk perception, and safety decision making.	Department of Civil Engineering / Desktop Computers	Following research questions were addressed: 1. Does incident emotional experience impact hazard-recognition skill? 2. Do construction hazards cause an emotional response? 3. Is there a relationship among hazards identified, total hazards in the environment, and danger assessment? 4. Is there relationship between incidental and integral emotional experience and danger assessment? 5. Is there a relationship among hazards identified, total hazards in the environment, danger assessment, and safety decisions? 6. Is there a relationship between incidental and integral emotional experience and safety decisions?	The analysis revealed that hazard-recognition tasks and exposure to hazards in the Augmented Virtuality (AV) environment generated a negative integral emotional state among participants, which influenced their subsequent risk assessments and safety decisions.	This study has several limitations which are given below: First, it is likely that the experimental manipulation with the movie clips was ineffective, but the authors do not have explicit empirical data to confirm this suspicion. Second, the student subjects recruited in this study do not entirely represent construction workers (i.e., ethnicity, age, injury, history, or work experience) Third, the augmented virtuality used in this study was computer-based application where participants navigated using the keyboard and mouse while receiving audio cues via headphones which makes this approach less immersive. Finally, a sample size of 73 is not ideal given the experimental design.

Table A2. *Cont.*

Author, Date/Settings	Aim of the Study/Participant Age Range	Research Questions/ Hypotheses	Field of Study/ Equipment (HMD) Used	Research Methodology/Method	Major Findings	Limitations of the Study
[73] / North Carolina State University, USA	The aim of the study is to create and evaluate immersive virtual reality (VR) and stereo-panoramic training environments tailored for construction safety training purposes. The study seeks to design and implement realistic VR and stereo-panoramic simulations that replicate construction sites and hazardous scenarios to assess the effectiveness of these immersive training environments in enhancing construction workers' safety knowledge, hazard recognition skills, and appropriate safety behaviours. / 53 (Not Specified) Age (18–29)	How does the implementation of virtual reality and stereo-panoramic environments in construction safety training impact safety knowledge acquisition, hazard recognition proficiency, and the adoption of safety behaviours among construction workers?	Department of Civil Engineering / Stereo-360 Camera recorder, Xbox controller	A paired two-sample *t*-test was conducted to check the statistical significance.	To improve the training content, the proposed method integrated various innovative training elements to develop a robust and personalized training protocol aimed at improving hazard recognition and management skills of construction professionals and workers. The result indicates that there was a significant improvement in hazard management score due to improvement in hazard recognition performance and the increase was the direct effect of the training.	The long-term impacts of the training remain unknown. Specifically, even though there was an instantaneous improvement in hazard recognition and hazard management performance of the workers, it is challenging to determine whether that improvement will be sustained in the long term. A costly high resolution video capture was needed for the current investigation. Additionally, the study was not built to separate the impact of the independent training components. Future studies might concentrate on putting the training technique into practice with actual construction workers and validating its efficacy with this distinct group.
[36] / Fukuoka Institute of Technology, Japan	The study's objective is to create a training program for firefighters that uses mixed reality (MR) technology to enhance their expertise in firefighting and rescue procedures. The research shows that it is possible to replicate fire events using MR technology and produce firefighter training scenarios that are accurate. The authors' goal is to assess how well the MR training method improves the performance of firefighters while lowering the possibility of accidents and fatalities during actual firefighting operations. / 7 (7M) Age (20–24)	Can a mixed reality-based training system improve the performance and safety of firefighters during fire suppression and rescue operations?	Firefighting Department / HTC Vive Pro and Core i7, 1080ti GPU with 16 GB RAM PC	The Wilcoxon signed-rank tests were performed, and results were compared.	The study demonstrated that the performance, safety, and confidence of trainee firefighters during fire suppression and rescue operations may all be considerably improved by the use of mixed reality (MR) technology in training. In addition, the trainees' situational awareness, decision-making, and team-work abilities were improved by the MR-based training system.	The study was conducted in a controlled laboratory environment with a small sample size and did not test the MR-based training system in real-life firefighting situations. While the study found that the MR-based training system improved trainees' performance and safety in simulated fire scenarios, it is unclear whether these improvements would translate to real-life situations. The study did not mention any technical limitations of the MR-based training such as system reliability, software hardware compatibility and or usability.

Table A2. *Cont.*

Author, Date/Settings	Aim of the Study/Participant Age Range	Research Questions/ Hypotheses	Field of Study/ Equipment (HMD) Used	Research Methodology/Method	Major Findings	Limitations of the Study
[48] / University of Houston, U.S.A.	This research study talks about developing a new approach for simulating crowd behaviour in scenarios involving multiple hazards. The study aims to create a simulation model that captures the dynamics of how panic emotions are generated and spread within a crowd when faced with various hazardous situations. This could include scenarios with multiple types of hazards occurring simultaneously or in rapid succession. The study's focus appears to be on understanding and modeling the complex interplay between different hazards and the emotional responses of individuals within a crowd, which can have implications for disaster management, crowd control, and safety planning. / (Not Specified) Age (18+)	The study enhances the traditional Reciprocal Velocity Obstacles (RVO) model with emotional contagion in multi-hazard circumstances. The study answers the following questions: What are the key factors that contribute to the generation and contagion of panic emotions in crowds under different types of hazards (e.g., fire, earthquake, terrorist attack)? How can panic emotions be modeled in a crowd simulation framework, and what are the key parameters that need to be considered? How can the proposed crowd simulation method be validated and evaluated, and what metrics can be used to assess its effectiveness?	Emergency Management / Desktop Computers	The authors used computational modelling like developing computer simulation techniques to model crowd behaviour in response to different types of hazards and emotional contagion. Next, the study involved the data analysis of identifying patterns and trends in crowd behaviour in different conditions. Finally, the proposed method validated and evaluated using established metrics and testing protocols to assess its effectiveness in simulating crowd behaviour.	Crowd behaviour simulation under multi-hazard environment is a very challenging problem, and this work present a novel evacuation simulation method by modelling the generation and contagion of panic emotion under multi-hazard circumstances. By comparing our simulation results with the ground-truth data and applying our algorithm in different virtual environments, the experiment results show that the overall approach is robust and can better generate realistic crowds as well as the panic emotion dynamics in a crowd in various multi-hazard environments.	There are several limitations in this current work, the first one is that the current method relies on some important assumptions, such as all agents in our scenario are treated equally in the face of hazards except the different personalities, thus they can percieve the danger level and be affected by the hazards once he/she enter into the influence radius of them. In real world, the exhibited scenarios are not very common. So, the improvement of sensing capability of the agents in an unknown multi-hazard scenario is needed. Secondly, many other personality traits and prior expertise may also affect the emotion changes and motion choices of each agent.

Table A2. *Cont.*

Author, Date/Settings	Aim of the Study/Participant Age Range	Research Questions/ Hypotheses	Field of Study/ Equipment (HMD) Used	Research Methodology/Method	Major Findings	Limitations of the Study
[70] / Purdue University—Department of Civil Engineering, USA	The study's goal is to investigate how wearable electroencephalogram (EEG) and virtual reality (VR) technology could be used to gauge construction workers' perceptions of hazards. Based on EEG data and VR experience, the study created a classification model that could discern between various degrees of workers' perceptions of hazards. / 28 (18M, 10F) Age (18+)	Can wearable electroencephalogram (EEG) and virtual reality (VR) technologies be used to classify workers' hazard-related perceptions in the construction industry?	Department of Civil Engineering / Wireless Emotiv EPOC+ Headset, Oculus Rift VR headset	An experimental research approach using VR and wearable electroencephalogram (EEG) were the two key technologies used in the study. While using VR to mimic various building site contexts and risks, the EEG was utilized to record the electrical activity of the participants' brains. Overall, the study took a quantitative approach, using objective measurements (EEG) and statistical analysis to examine the connection between employees' perceptions of hazards and their brain activity in response to virtual reality (VR) simulations of dangerous scenarios.	The study offers encouraging proof that wearable EEG and VR technology may be applied to objectively evaluate employees' perceptions of hazards, which can assist in identifying possible safety issues and averting accidents in the construction sector.	The article has several limitations such as small sample size, limited diversity as participants were selected from a single construction management program, which may limit the generalizability of the findings to more diverse populations of construction workers, limited VR scenarios lacks the different hazards exposure which may not capture the full range of hazardous conditions encountered in construction environment, lacks the field validation and potential confounding factors.
[33] / Civil Engineering Laboratory, Beijing China.	The purpose of the paper is to use multimodal monitoring approaches to explore and analyze the cognitive processes of people working on construction sites who are exposed to various sorts of dangers. / 48 (35M, 13F) Age (18+)	What are the cognitive demands of hazard recognition in construction workplaces and how can they be measured using multimodal methods?	Cerebral Activities and Pupil Response in Civil Engineering / Tobii Glasses II—Eye Tracking	ANOVA Test/Correlation Analysis	The study's findings advise modelling building sites with various hazard types, complexity creates various cognitive demands and patterns that needs to be handled differently. In addition, the use of multimodal monitoring in experimental protocols conducted in realistic hazard scenarios help bridge existing gaps.	Sample size is too low to generalize the research results.

Table A2. *Cont.*

Author, Date/Settings	Aim of the Study/Participant Age Range	Research Questions/ Hypotheses	Field of Study/ Equipment (HMD) Used	Research Methodology/Method	Major Findings	Limitations of the Study
[46] / Hong Kong	The aim of the study is to investigate the feasibility and effectiveness of using a single uniaxial gyroscope as a tool for detecting the potential risk or occurrence of lateral ankle sprains. / 10 (10M) Age (20+)	Can a single uniaxial gyroscope be effectively utilized for the detection and prediction of lateral ankle sprain hazards?	Sports / Wearable inertial motion sensor, VICON, Gyroscope	Statistics/Results comparisons	A robust positive association was identified between the peak twisting velocity recorded by the gyroscope and the peak ankle inversion velocity measured by the optical motion analysis system for assessing the risk of a lateral ankle sprain.	The study has restricted the participants to male leisure athletes exclusively. The research methodologies are suitable for these individuals, since they engaged in court sports that require lateral, sideward, or cutting motions. This research does not include female athletes in its testing.
[35] / Center for Modeling, Simulation, and Imaging in Medicine, Troy, NY, USA	The research aim is to develop and assess a virtual reality (VR) simulation of an operating room that incorporates AI guidance, specifically focusing on the scenario of a fire emergency. / 53 (39M, 14F) Age (23–75)	What is the design process of a virtual reality operating room integrated with AI guidance for surgical procedures, and how can it be effectively validated through the creation and testing of a simulated fire scenario?	Medical Training / HTC Vive/Core i7 16 GB RAM	The questions were analyzed by calculating the mean, standard deviation (SD), and percent of responses that were greater than six on a 7-point scale. Shapiro-Wilks test, and Friedman's test were performed during the data analysis.	AI guidance-enabled VR simulator for operating room fire scenario demonstrated the potential to further enhance training effectiveness of the VR simulator and improved the user's performance on the simulation.	The simulator only provides the fire extinguisher training to extinguish the fire, however, others fire extinguishing tools such as fire blankets should be provided in the simulator.
[28] / University of Southern California	The study aims to assess whether using VR technology as a training tool can effectively improve construction workers' understanding of robotic teleoperation, their practical skills in operating robots remotely, and their adherence to safety protocols while performing such tasks. / 50 (48M, 2F) Age (18+)	The study investigated the impact of VR-based training on knowledge acquisition, operational skills, and safety behaviour while working with the robot compared to a more traditional, comparable in-person pedagogical model and answer the following research questions: 1. How does VR-based training impact knowledge acquisition for construction workers compared to the traditional training methods? 2. How does VR-based training impact construction workers' safety behaviour, compared to the traditional training method? 3. How does VR-based training impact construction workers' operational skills, compared to the traditional training method?	Construction-site workers / HTC Vive HMD, PC NVIDIA GeForce GTX 1080 Graphics Card, Arduino Pro, Virtuix Omni VR Treadmill	A mixed research methodology (Quantitative and Qualitative) approach was followed. ANOVA test was performed and statistical models such as mean ratings were used in the study.	VR-based education works well especially when the content or skills being learned heavily rely on visual or spatial information or spatialization. Virtual Reality (VR)-based training has been considered and investigated as a safe and cost-effective training method that allows workers to be exposed to hazardous tasks with negligible actual safety risks in comparison to existing training methods (hands-on, lecture-based, apprenticeship training). VR-based training has advantages in terms of safety, scalability, and overcoming language barriers.	VR-based training requires significant effort and computing powers, in future studies, researchers might compare the costs of implementing VR-based training compared to in-person training. Only one professional trainer was hired due to pandemic situation to evaluate trainees' performance with the actual robot both quantitatively and qualitatively. Using a second evaluator can ensure having inter-rated agreement on the quantitative scores and qualitative assessment in future studies. Future studies should also collect participants' feedback on their experience with VR-based training.

Table A2. *Cont.*

Author, Date/Settings	Aim of the Study/Participant Age Range	Research Questions/ Hypotheses	Field of Study/ Equipment (HMD) Used	Research Methodology/Method	Major Findings	Limitations of the Study
[31] / Myers-Lawson School of Construction, Virginia Tech, U.S.	The project aims to increase the effectiveness of the current construction training programs through developing a training platform for instructor-in-the-loop, group-based VR training. / Not Specified Age (18+)	Can group-based virtual reality training effectively enhance the abilities of highway construction workers in recognizing, evaluating, and controlling hazards within their work environment?	Highway—Construction Sites Workers / Cyclorama 360 degree Projection Environment	Designed scenarios are evaluated by an experienced construction safety instructor as compared to linear and passive lecture-based training.	The proposed approach has significantly reduced work zone accidents, improved safety and health and contribute to economic benefits nationwide.	More formative study is required to identify hazardous factors from videos taken from real highway construction worksites and more interviews needs to be conducted to training instructors to investigate the critical past incidents.
[40] / National Future Farmers Association (FFA) Convention and Expo, Indianapolis	The study examines the effect of a VR intervention (Virtual Reality Intervention for Safety Education; VRISE) on a behavioural intention for occupational safety and identifies a psychological mechanism that shows how the immersive technology works. / 291 (161M, 130F) Age (12–16)	Hypothesis: VR Group participants will increase perceived threat of tractor rollover accidents and the heightened perceived threat in turn will increase the users' behavioural intention to operate tractor safely. RQ: Will the experience of immersion mediate the effects of VRISE on perceived threat to tractor rollover accidents and the users' safety behaviour intentions?	Agriculture–Tractor Safety Education / HMD/TV Screens	Statistical analysis such as Ordinary Least Square (OLS), and Logistic Regression path analysis modeling tools and PROCESS model to test the hypotheses and RQ.	The VR system impacts immersion experience and perceived threat, and in turn influences two different types of tractor safety behaviours, safe tractor operation and installation of ROPS, which are equally important to preventing tractor roll over injury events.	Due to hundreds of students crowded in the exhibition hall where the booth was located, we could not execute random assignment systemically nor measure the time taken for each participant's trial. The future research needs to test the similar hypotheses under more tightly controlled situations, such as a laboratory experiment. The participants were restricted to high school students, although VRISE could be effective in other age groups, such as middle school students or even people in their twenties and thirties. Future research should expand the target of VR interventions and test their effectiveness across different age groups.

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