KEY ORGANISATIONAL ATTRIBUTES FOR DEVELOPING A MATURITY MODEL: ADOPTING IMMERSIVE TECHNOLOGIES IN CONSTRUCTION SAFETY TRAINING

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Immersive Technologies (ImTs), such as virtual reality (VR) And augmented reality (AR) Offer a promising avenue to enhance safety in the construction industry by enriching training with improved knowledge, skills, effectiveness, and accessibility, while promoting a robust safety culture. Despite recognising the value of integrating ImTs into construction safety training and the considerable research devoted to its technical aspects, organisations face challenges in its adoption. The lack of standardised frameworks and reliance on outdated training methods are major barriers, hindering the full realisation of ImT's benefits for safety training. This study aims to establish an organisational readiness model that identifies critical attributes for successful ImTs implementation. Through a combination of systematic literature review (SLR) And questionnaire-based expert verification, fourteen organisational attributes were identified, and grouped into three categories: people and organisational structure, technology, and lifecycle costs. This insight could help organisations better understand their capabilities and prepare plans for implementing ImTs in safety training. Highlighting the need for an ImTs maturity model tailored to organisational needs, this research underscores the potential of ImTs to revolutionise safety training in construction.

Keywords: Immersive Technologies; organisation readiness; construction safety; health and safety; maturity model; training

INTRODUCTION

In the context of safety training in the construction industry, immersive technologies (ImTs) Can be described as ‘open-world exploratory experience’ or ‘guided experience’ where workers can navigate and interact with virtual environments to conduct safety tasks and complete activities to fulfil the training requirements (Kamat *et al.,* 2011). Various forms of ImTs have been used in safety training, including virtual reality (VR), augmented reality (AR), mixed reality (MR), 360-degree video, haptic technology, immersive audio, gesture recognition, etc. In terms of safety, these

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types of ImTs can have a significant impact on human behaviours. Previous studies have shown the effectiveness of ImTs where they provide solutions to perennial safety problems encountered in the construction site, such as unsafe working conditions (Dong *et al.,* 2018; Yan *et al.,* 2022), inadequate training (Eiris *et al.,* 2020), lack of awareness and engagement (Swallow and Zulu, 2023) And insufficient preparedness for emergencies hazards (Goulding *et al.,* 2012). For example, ImTs have been used to create virtual reality (VR) Simulations that allow workers to practice hazardous tasks in a safe and controlled environment (Greene *et al.,* 2019). This not only improves their skills and confidence but also reduces the risk of accidents and injuries on the actual construction site. Additionally, augmented reality (AR) Technology has been used to provide real-time safety information and warnings to workers, helping them identify potential hazards and take preventive measures (Cheng and Teiser, 2013). These innovative applications of ImTs have significantly enhanced safety training in the construction industry and have the potential to revolutionise the way safety is approached in the future. Despite the benefits that ImTs can offer, adoption and diffusion of ImTs across the construction industry have been low compared to other industries such as aviation. This sluggish adoption was found to be attributed to numerous root causes, such as the increasing costs of hardware and software (Ahmed, 2019; Onososen *et al.,* 2023; Zoleykani *et al.,* 2023), insufficient expertise (Sidani *et al.,* 2022), fragmentation (Eiris *et al.,* 2018; Perlman *et al.,* 2014), lack of collaboration and reluctant to change in adopting new technologies (Sidani *et al.,* 2022).

Despite research identifying key attributes for effective ImTs adoption, organisations face challenges in applying these insights for successful integration and benefits maximisation (Abulrub *et al.,* 2012). To adeptly navigate the intricate implementation of ImTs, particularly in bolstering safety training within the construction industry, the adoption of a maturity model is imperative. Research has shown that organisations with maturity models are more capable of improving safety performance for assessing and advancing their capabilities. The study was conducted by Jääskeläinen *et al.* *(*2020) Not only furnishes organisations with a comprehensive roadmap for enhancing safety practices but also underscores the imperative of structured safety evaluations, aiming to eradicate incidents and foster a robust safety culture. Furthermore, Goncalves Filho and Waterson (2018) Identified a notable uptrend in the utilisation of maturity models to evaluate safety culture across various sectors such as construction, oil and gas, and healthcare. By leveraging maturity models, organisations can meticulously assess safety practices and cultural nuances at different maturity levels, thereby reinforcing the criticality of structured methodologies like maturity models in navigating organisational readiness towards safety enhancement. In the context of this research, there exists a research gap in elucidating the specific factors pivotal for the successful integration and maximal benefits realisation of ImTs in the context of safety training within the construction industry. Hence, this paper aims to craft such a model, providing a systematic roadmap for construction industry organisations to adopt and optimise ImTs in safety training. This model could pinpoint improvement needs, aid strategic planning and resource allocation, and promote a culture of safety and innovation. To achieve this aim, this study utilises pragmatism, a philosophy that emphasizes practical solutions and combines various research methods. It employs systematic literature reviews (SLR) Alongside expert verifications through questionnaires, aiming to identify essential attributes for organisational readiness and successful ImTs implementation in safety training, thus establishing a benchmark for effective practice.

METHOD

As illustrated in Figure 1, literature reviews and experts' verification surveys were used in the research process. Phase 1 of this research involved SLRs to identify existing organisational readiness attributes for implementing ImTs. Phase 2 of the study involved an expert verification process using quantitative surveys to refine and verify the factor descriptions for survey instruments. The comprehensive descriptions of all phases are outlined in the subsequent sections.

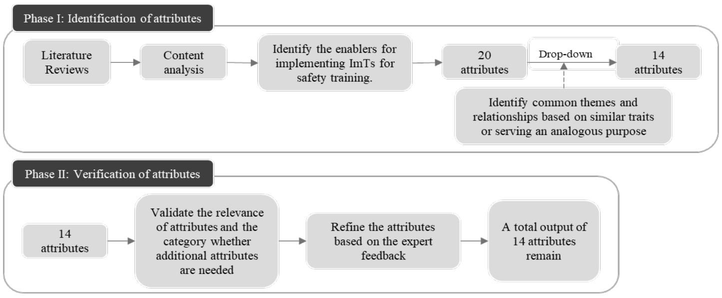

Figure 1: Research process

Phase I: Systematic Literature Review

This systematic literature review (SLR) Employed the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) Methodology for the literature search. Two primary databases: Scopus and Web of Science were utilised. The advanced search strategy for the SLR incorporated keywords included (("construction" OR "built environment") AND ("health and safety" OR "safety" OR "health" OR "occupational safety and health") AND ("training" OR "intervention*") AND ("immersive technolog*") OR ("virtual reality") OR ("augmented reality") OR ("mixed reality")). The first step is to set search terms under the title, abstract, and keywords. In the second step, 543 papers were produced, which were further refined based on the following inclusion criteria: 1) The articles were all devoted to ImTs; 2) Articles that discuss health and safety in construction; 3) The articles are all written in English; 4) The full text of all articles must be available. The publications include journal articles, conference proceedings, book chapters, and dissertations. A paper that merely discussed safety and health training without proposing any technologies for predicting or preventing was deemed ineligible. After removing 221 irrelevant articles, 322 articles were left for further analysis. Titles and abstracts were assessed to exclude articles not related to the topic. Using Mendeley reference management software, 155 duplicate records were removed, and 167 relevant articles were identified and screened.

The SLR helped identify 20 attributes, which were initially called 'enablers' that facilitate the implementation of ImTs for safety training, without grouping into any category yet. These 20 attributes were undergone refinement process based on similar trait or characteristics aspects. To streamline the process, the 20 identified attributes were grouped into categories based on their similarities and relevance to implementing ImTs for safety training. These attributes were analysed to identify common themes and relationships, ensuring those with similar traits or purposes were clustered together. During this categorisation process, the team assessed each attribute for its functionality and any overlap with other attributes. To improve clarity and applicability, the team combined some traits, resulting in a final list of 14 modified attributes. These attributes were categorised into People, Process, and Technology (PPT) To improve comprehensiveness and facilitate better understanding, such as knowledge management (Hosseini, 2014). This integration has gained widespread recognition as a key component of enhancing construction organisation development. In the late 1990s, Bruce Schneier popularised the PPT framework, which originated in the early 1960s (Ali, 2023). Numerous industries have used this framework to optimise employee performance and tool efficiency. However, this categorisation was then revised to align with attributes that would serve the intended research purpose. For example, People and Organisational Structure: Broadens the focus beyond individuals to include how the organisation is structured, providing a more complete picture of human and structural aspects. This resulted in three categories, named PTC framework: 1) People and Organisational Structure, 2) Technology, and 3) Lifecycle Cost. These categories were then further divided into subcategories.

Validating the proposed groupings and achieving consensus required consultation and discussion within the research team. A refinement of the classifications was made as needed to align them with the overarching objectives. As a result of a thorough discussion with the team, they provided valuable feedback to ensure the categorisation process was relevant and accurate. Overall, the derivation of attributes within each category was guided by a combination of systematic analysis, collaborative decision-making, and input from the research team. As a result, the 14 attributes were categorised in the PTC framework mentioned above. A total of 14 attributes were proposed and their descriptions were refined to accurately reflect their functions.

Phase II: Verification Process

To verify the appropriateness of the 14 attributes in the PTC framework, a verification survey was conducted. The questionnaire was completed by 15 out of 23 experts recruited through the research team's network and social media (i.e. LinkedIn). The criteria for selecting experts require candidates to meet these qualifications: all experts have a minimum of 5 years of work experience in construction, an academic degree in relevant fields, and membership in a professional body with research expertise in environmental, health, and safety management. This ensures that chosen experts have the necessary skills and knowledge to contribute effectively to the group's decision-making process, providing a well-rounded understanding of the construction industry. Additionally, the inclusion of both academic and industry-related qualifications serves to guarantee that the selected experts possess a comprehensive understanding of the multifaceted dynamics of the construction industry. The verification survey included questions about experts' opinions regarding the appropriateness of the attributes' descriptions related to organisational readiness needs for implementing ImTs and if the descriptions adequately reflect the requirements of implementing ImTs. This survey was performed to gather input on the organisation's readiness capabilities and to modify the attributes description for future surveys. A total of 15 respondents were selected from two countries, the United Kingdom and Malaysia, to participate in the survey. The survey was distributed online and collected responses from selected respondents. The data collected was analysed using statistical methods.

FINDINGS AND DISCUSSIONS

1) SLR

The SLR identified 14 attributes (illustrated in Figure 2) Crucial to implementing ImTs for safety training in the construction industry.

2) Verification using survey

In the survey, experts were asked to evaluate the relevance of attribute descriptions, especially in support of ImTs deployment for safety training. Experts were also encouraged to suggest potential capability attributes that might have been overlooked. The questionnaire was filled out by 15 out of 23 experts, representing a response rate of 65%. As a result, the experts unanimously agreed that the proposed attributes are appropriate and necessary for ImTs implementation, allowing seamless alignment with existing attributes. All the attribute descriptions have been evaluated by experts and have reached an agreement and more than 80% of respondents regarded the attributes as relevant as shown in Figure 2. This indicates a high level of consensus among the experts regarding the quality and appropriateness of the attribute descriptions. This level of consensus among experts indicates that the attribute descriptions are likely to be accurate and suitable for the intended purpose, providing a solid foundation for further analysis and decision-making. Accordingly, all 14 attributes were validated and categorised into three distinct categories: 1) People and Organisational Structures, 2) Technology, and 3) Lifecycle Costs. A categorisation framework underpins the development of an ImTs implementation maturity model, which enhances organisational readiness and efficacy in leveraging ImTs for safety training.

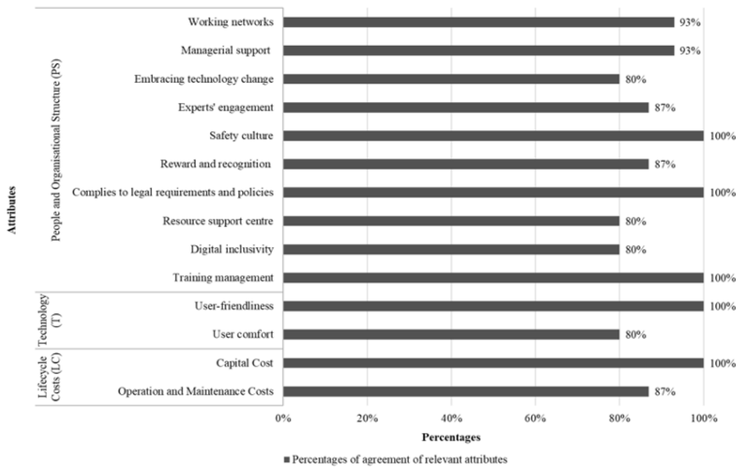

Figure 2: Verification survey's result

Figure 2 illustrates a percentage of agreement among experts for all 14 proposed attributes. Specifically, in the People and Organisational Structure (PS) Category, three attributes—safety culture, compliance with legal requirements, and training management—garnered 100% agreement on their descriptions. Similarly, user-friendliness attributes in the Technology (T) Category and capital cost attributes in the Lifecycle Cost (LC) Category also attained 100% agreement. Based on the verification survey result, these comprehensive attributes underline the robustness and coherence of the attribute description for the ImTs implementation in safety training.

Several areas for improvement were pinpointed, and recommendations were provided to facilitate the ongoing refinement of the descriptions. Some of the key suggestions included the clarification of language in the descriptions to enhance conciseness and comprehension. These recommendations were elaborated upon in the People and Organisational Structure (PS), Technology (T), and Lifecycle Costs (LC) Sections (below Table 1), resulting in a simplified and more easily understandable presentation. Consequently, we developed clear and concise descriptions that could be applied to all cases after reaching a consensus. Based on feedback from experts, the updated descriptions of attributes are shown in Table 1.

Domains	Proposed attributes	Description
People and organisation structure (PS)	PS1. Working networks	Working networks refer to knowledge and social networks that facilitate the exchange of information and resources among employees to build and use ImTs in safety training. For employers, social networks involve the professional and digital platforms that facilitate communication and collaboration among employees. These networks, whether online or offline, contribute to internal connectivity, knowledge sharing, and team collaboration.
	PS2. Managerial support	Managers drive the implementation of ImTs in safety training by ensuring that the resources (e.g., people, software, hardware, documentation, etc) Required are available. They are also responsible for monitoring and evaluating the effectiveness of using ImTs in safety training. In addition, they should provide ongoing support to ensure that employees can use ImTs effectively.
	PS3. Embracing technology change	Both the organisations and its employees embracing technology change requires a mind-set shift, staying informed about emerging technologies, investing in research and development, and fostering a culture of innovation. Using ImTs for safety training will likely involve significant technology change in an organisation. Therefore, the capability of embracing technology change is essential.
	PS4. Expert engagement	Experts' engagement refers to involving individuals skilled in these domains to optimise ImTs implementations. They provide guidance, advice, and expertise to identify risks and challenges, develop strategies, and ensure successful ImTs implementation within an organisation.
	PS5: Safety culture	Safety culture represents practices, beliefs, and attitudes that prioritise the safety and wellbeing of employees in the organisation. It involves creating a safety mind-set and behaviour to facilitate the implementation of ImTs for safety training. This includes providing proper training and equipment maintenance, empowering employees to voice concerns and participate in decision-making, and establishing and enforcing clear safety protocols. By having a strong safety culture, organisations can maximise the benefits of ImTs and protect their employees' health and safety.
	PS6. Reward and recognition	Recognising and rewarding ImTs implementation efforts entails acknowledging and motivating contributing employees. This can be achieved through rewards, career growth prospects, skill enhancement, and public recognition.
	PS7. Complies with legal requirements and policies	Ensuring ethical, safe, and legally sound immersive technology (ImTs) Safety training involves adhering to strict compliance with various legal aspects, including the General Data Protection Regulation (GDPR) And health and safety regulations. This encompasses implementing a clear data sharing policy, which outlines how data is collected, used, and protected during training, and an intellectual property (IP) And copyright policy that defines ownership and usage rights for ImTs content developed for training programmes. This policy ensures transparency, privacy, and security, while safeguarding IP rights, promoting responsible and innovative practices in ImTs safety training.
	PS8. Resource support centre	Establishment of resource support centre for ImTs in safety training provides a range of resources and services to support the ImTs implementation like VR and AR in safety training. For example, it could provide tutorials for how to use ImTs in safety training, organising related workshops, offering technical support, fostering collaborations, and providing customisation services.

	PS9. Digital inclusivity	Digital inclusivity in ImTs safety training means ensuring accessibility for all, irrespective of abilities or backgrounds. To achieve this, organisations should evaluate needs, create accessible content, offer multilingual options, optimise for low bandwidth, ensure physical access, educate trainers, and comply with standards.
	PS10. Training management	Training management encompasses the process of identifying training needs, planning, executing, and evaluating training programs within an organisation. Key steps could include audience identification, technology selection, environment setup, content development, performance monitoring, risk assessment, goal setting, and continuous feedback for program enhancement.
Technology (T)	T11. User-friendliness	User-friendliness refers to the ease of learning or understanding of hardware or software interfaces. A good immersive experience should be intuitive, natural, and user-friendly, making technology more accessible, and simple to control.
	T12. User comfort	User comfort in immersive safety training involves ensuring physical comfort with ergonomic VR/AR devices, minimising motion sickness through smooth tracking, providing clear and spatial audio, controlling temperatures, promoting safety awareness, considering training duration and incorporating breaks, allowing customisation of settings, offering user training, and implementing feedback mechanisms.
Lifecycle Costs (LC)	LC13. Capital costs	Capital costs encompass a range of essential elements, including hardware and software procurement of ImTs, and the provision of training for personnel. An organisation needs to consider these upfront expenses as they play a critical role in shaping the feasibility and success of integrating ImTs into safety training programs.
	LC14. Operation and Maintenance costs	Operation and maintenance costs could include software updates, hardware maintenance, content updates, technical support, staff training, and regular upkeep of equipment and infrastructure. An organisation needs to consider these costs when implementing immersive technology, as they ensure the technology remains functional, up-to-date, and secure, providing users with a seamless and reliable experience over time.

Table 1: Verified organisational attributes needed to incorporate ImTs into safety training.

People and Organisational Structure (PS)

The first category, People and Organisational Structure (PS) Plays a pivotal role in fostering a robust safety culture, permeating interpersonal dynamics, work performance, and decision-making. The findings highlight the important of safety culture in PS, which aligns with Zhao and Lucas (2015), who emphasize the deeply affects all aspects of daily life, shaping daily routines through ingrained habits. This assertion is corroborated by 100% of experts, underscoring its significance attributes in Safety Culture (PS5). By synergising this component within the PS category in the initial stage, organisations bolster resilience and adaptability, integrating a safety culture objective into ImTs implementation. Embracing a holistic approach to safety ensures that safety considerations become intrinsic to organisational practices, thereby enhancing overall effectiveness, and mitigating risks. Moreover, supplementing these attributes with other essential elements, unanimously supported by experts, further strengthens Compliance with Legal requirements and Policies (PS7), and Training Management (PS10), resulting in a comprehensive and proactive approach to safety implementation.

Despite slightly lower levels of agreement on attribute descriptions, experts reached 93% regarding Working Networks (PS1) And Managerial Support (PS2). In order to ensure clarity and precision, experts recommend that managers involved in these aspects be further defined. Based on the expert's comment, working networks should also be able to define what social networks mean to employers, according to the experts. Also, the experts agreed that these managerial support networks should be able to identify who a manager works for. This has led to an update in the description and detail can be found in Table 1.

In contrast, descriptions of attributes such as Experts' Engagement (PS4) And Reward and Recognition (PS6) Received an impressive 86% agreement from experts. Others, such as Embracing Technology Change (PS3), Resource Support Centre (PS8), and Digital Inclusivity (PS9), received 80% approval. Although there was lower agreement among experts regarding Reward and Recognition (PS6), they did not provide any comments or recommendations for updating the descriptions of attributes. Therefore, the descriptions of these attributes will remain unchanged. However, as for the other attributes, there were some comments from experts that were deemed irrelevant as they stated that the titles of some of the attributes were unclear, and therefore were disregarded as irrelevant. As a result, no changes will be made to the descriptions of these attributes.

Technology (T)

The second category, Technology (T), encompasses equipment integral to programs aimed at improving skills and enhancing high performance in safety. Employing appropriate equipment, characterised by ease of learning and understanding of hardware and software interfaces, can contribute significantly to optimal results and effectiveness in this category. Thus, it comes as no surprise that expert opinions on user-friendliness (T11) Attributes description have reached unanimous agreement, with 100% agreeing that they accurately describe how ImTs is implemented for safety training.

The user comfort (T12) Attribute description, however, was more controversial, with only 80% approval. This discrepancy stemmed from expert commentary emphasising ImTs maturity significance. Experts highlighted that only through prolonged usage and continuous monitoring of ImTs solutions can any potential adverse effects become apparent. Additionally, there were suggestions to merge the concept of user comfort with the concept of user friendliness due to their similarity to increase engagement of ImTs. Nevertheless, after extensive and thorough discussions among the team research, it was determined that user-friendliness primarily relates to user features and an intuitive application interface, while user comfort focuses on the overall impact of the ImTs application during and after the application has been used, including factors such as ergonomic design, usability, and user satisfaction beyond mere ease-of-use.

Lifecycle Costs (LC)

The third category, Lifecycle Cost (LC), encompasses both fixed capital and working capital utilised for equipment acquisition or resource hiring. The LC includes capital costs, operating expenses, and maintenance costs. Experts unanimously supported Capital Cost (LC13) In this category, with a 100% approval rate. These upfront expenses for hardware and software procurement, as well as training for personnel, are crucial factors to consider when integrating ImTs into safety training programs. The capital costs associated with acquiring the necessary equipment and providing comprehensive training are essential investments that can greatly impact the feasibility and effectiveness of ImTs implementation in enhancing skills and improving safety performance.

As another LC attribute, Operation and Maintenance Cost (LC14) Earned significant agreement, earning an impressive 86% approval rating, reinforcing the importance of meticulous cost considerations throughout technology implementation lifecycle. The description of this attribute remains unchanged as no comment was provided by experts who disagreed with it.

CONCLUSIONS

In conclusion, while the fundamental attributes of a successful ImTs implementation are well established, certain drawbacks still hinder the applications of this technique for health and safety training within the construction industry. There is, however, an opportunity to address these challenges by evolving robust attributes that can be developed to address these issues. The findings of this study revealed that all attributes exert a profound influence on organisational readiness for implementing ImTs in safety training, with particular emphasis on safety culture, compliance with legal requirements and policies, training management, user-friendliness, and capital cost—all of which garnered unanimous agreement on attribute descriptions by experts. This implied that these attributes comprehensively capture people and organisational structure, technology, and lifecycle cost considerations. By categorising and prioritising necessary attributes needs based on their applicability and relevance to ImTs implementation in construction safety training, organisations can effectively overcome these hurdles. A robust set of attributes can provide a clear road map for organisations to follow when developing their ImTs training programmes, allowing them to identify the necessary resources, identify potential risks, and develop strategies to mitigate them. Hence, for further research development, the utilisation of these identified attributes will be instrumental in constructing a maturity model (i.e., Technology Readiness Model), establishing a foundational framework to ensure organisations are thoroughly equipped to seamlessly integrate ImTs into safety training.

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