Investigating the Implementation of Immersive Technologies Within On-Site Construction Safety Processes

Abstract

Purpose

The benefits of integrating immersive technologies (ImTs) within a construction safety context are acknowledged within the literature, however its practical application on construction sites remains low. Whilst research into the integration of ImTs within the construction industry is underway, most have viewed this from a broader adoption context or within educational settings, and not specifically from a practical on-site safety perspective. Therefore the purpose of this study is to address the contributing factors to its integration within on-site safety processes, using the experiences of active construction professionals.

Study Design/Methodology/Approach

This study adopts a qualitative approach. Data was collected through online focus groups involving UK based construction professionals with experience in using ImTs, recruited using selective sampling. Data sets were subsequently analysed using inductive thematic analysis and are presented within key themes.

Findings

The results showed that amongst the experienced construction professionals, the use of ImTs specifically for on-site safety applications (including inductions/training/workshops) was rare on projects. The findings identified various contributing factors related to the integration of ImTs, including the potential improvements in on-site safety practices such as enhanced communication of hazards, safety planning, engagement during training and more accurate risk assessment. Critical challenges, concerns and frustrations included a lack of engagement from senior level management, inadequate leadership, limited investment, a need for digital expertise, fear of complacency and the acceptance of ImTs within existing safety processes from the wider project team.

Originality/Value

This study provides a fresh perspective to this field by using practical accounts from active and experienced on-site construction professionals. This study supports the integration of ImTs within the construction industry, presenting key contributing factors influencing its integration within on-site safety processes. These factors can be considered by industry adopters, and includes the rationale, challenges and potential on-site benefits of ImTs.

Keywords
Construction industry, immersive technology, technology adoption, safety.

Introduction

Construction is considered to be one of the most dangerous of all industries (Mohammadi et al., 2018) and is accountable for the highest number of fatal accidents among all the major sectors within Great Britain (HSE, 2022). Therefore, safety remains a high priority for the construction industry, and techniques which have the potential to reduce risk or improve site safety inevitably attract interest. The construction sector is also experiencing a digital revolution. From a UK perspective, this has resulted in a growing demand for the integration of a wide range of technologies, used for a variety of on-site applications. Noticeable developments in immersive technologies (ImTs) within such fields as entertainment and gaming have allowed high-performance devices to become more accessible (Froehlich & Azhar, 2016). As such, its practical application within the construction industry is now gaining increased scholarly attention (Alizadehsalehi et al., 2021; Prabhakaran et al., 2022). The benefits of using ImTs have been discussed by many researchers (DelaCruz & Dajac, 2021), often suggesting these digital technologies provide the answer to improve safety (Hamil, 2019). ImTs can offer an interactive, virtual, risk-free environment which can be the ideal solution for safety purposes, such as training and communicating safety risks (ElGewely & Nadim, 2020; Olugboyega & Windapo, 2019). However, whilst research into the potential gains of using ImTs within safety training is well developed (Muhammad et al., 2020; Sacks et al., 2013), data collected from practical, industry-based safety applications are limited (Swallow & Zulu, 2020a).

Despite the reported benefits of ImTs within the literature and the importance of safety acknowledged in industry, researchers have identified that ImTs are not widely adopted on construction projects for practical uses (Delgado et al., 2020; Ghobadi & Sepasgozar, 2020; Khan et al., 2021; Okoro et al., 2022). This low adoption has resulted in researchers calling for further exploration into the contributing factors, specifically asking for reasons why these are not common within on-site safety processes (Babalola et al., 2023). Whilst research has begun to explore the broader adoption factors, this knowledge is limited from a safety application context. Therefore, this study is timely, aiming to provide a practical industry insight into the key contributing factors influencing the integration of ImTs, specifically from an on-site safety application perspective.

Immersive Technology within the Construction Industry

Adoption of Immersive Technology in Construction

The term ‘immersive technology’ refers to a collection of technologies that allows the user to access a digital environment that emulates physical surroundings, this includes the use of virtual reality (VR) and augmented reality (AR) (Suh & Prophet, 2018). These technologies are continuously developing and becoming a realistic option within construction applications, as stated by Okoro et al. (2022) “*the usefulness of technology for managing projects in the construction industry is indisputable”*. However, many have acknowledged the UK construction industry's slow rate of technological adoption, with repeated claims of lack of investment and fragmented senior level leadership (Farmer, 2016). In relation to ImTs, Smith (2020) suggests *“now is the time to start paying attention... now is the time to start experimenting*”.

Academic research investigating ImTs within the construction industry is underway, with many focusing on its uses, benefits and challenges to its wider scale adoption (Prabhakaran et al., 2022). For example, Delgado et al. (2020) used thematic analysis and questionnaires involving a combination of industry and academic participants. Their study identified 42 limiting and driving factors, which were ranked using quantitative analysis. They concluded that improvements in project delivery and corporate performance were core benefits, however identified that high costs in equipment and training, unsuitability and '*immature technologies*' were limitations. Ghobadi & Sepasgozar (2020) took a qualitative approach within an educational setting, using interviews with academic staff and students. They concluded that the barriers to further adoption included high costs, software and hardware requirements and low accessibility. It is noted that whilst investigation into contributing factors surrounding the industry adoption is being documented, these are explored broadly and without a specific application focus.

Immersive Technologies within a Safety Context

Research into the use of ImTs specifically for safety purposes has been a topic of increased scholarly activity. To investigate the extent of this research, Swallow & Zulu (2020a) carried out a scoping study and suggested there is limited academic research from a practical, industry application perspective. They concluded that research in this field primarily focuses on safety training or within educational settings, in particular its application for hazard recognition training (Afzal & Shafiq, 2021; Perlman et al., 2014) and in safety equipment training (Li et al., 2012). Similarly, a review of literature in this field was conducted by Babalola et al. (2023) who also noted that studies focused on hazard identification and training. Their paper suggested further research should be carried out in this field, specifically with regards to the application of ImTs, their effectiveness and to explore reasons for its low practical adoption. DelaCruz & Dajac (2021) also discovered a number of research gaps including the need to consider the financial implications of integrating ImTs. Their research also identified a lack of live project VR uses, and recommended capturing views from industry practitioners and higher-level managers who have financial decisions over its implementation.

This said, studies within the field that explore practical impacts, involving industry-based participants, are beginning to receive attention. For instance Sacks et al. (2015) argued that ImTs can influence communication between the design and construction teams to improve safety in design. Muhammad et al. (2020) used questionnaire surveys to compare the use of virtual reality to traditional 2D site layout planning methods. This research concluded that whilst more time-consuming, the VR process was more effective in collision detection. Afzal & Shafiq (2021) also explored the use of VR in practice and simulated site safety instructions for construction crews. Like in the findings of Chun et al. (2012), the research reported an enhancement in hazard recognition and improvements to multilingual communication. Whilst the studies within this field show significant insights into the various uses and benefits of ImTs for safety applications, the driving and challenging factors affecting the practical integration of ImTs for these purposes is limited. Researchers have advocated the need for further research in this field (Babalola et al., 2023; DelaCruz & Dajac, 2021) which this study seeks to develop.

Research Methodology

Research Approach

This study adopted a qualitative approach, allowing the researchers to gather in-depth accounts of the thoughts and experiences of the participants for analysis. This approach included data collection through a series of focus groups with active construction professionals, the data was subsequently analysed using a thematic framework. The use of focus groups is a reliable and popular method in many fields (Guest et al., 2017) and involves the assembling of individuals into groups to discuss a specific topic, moderated by the researcher (Nyumba et al., 2018). The rationale for adopting focus groups for this study centred around the encouragement of communication (Gibbs, 1997) between active construction professionals to share their views and experiences. Using this open environment, the grouped participants discussed pre-determined questions and were able to comment on the views of others. This form of interaction also allows participants to pose further questions to the group and captures these responses.

Data Collection

The focus groups in this study were conducted in an online environment, this was primarily due to the necessity of following COVID-19 lockdown restrictions. Aside from the virtual nature of the interaction, conducting focus groups in this way is similar in most aspects to that of traditional face-to-face approaches, although can be prone to loss of internet connectivity (Nyumba et al., 2018). Using an online platform, participants were able to communicate with others and had the added ability to share information via chat functions. Online virtual platforms aim to provide flexibility and accessibility for participants, whilst accurately capturing the data for analysis (Lobe et al., 2020).

The quantity of online focus groups drew from the works of Guest et al. (2017) who suggest that between 3 and 6 focus groups are needed in order to identify up to 90% of themes on a given topic. To determine the size of each focus group this study considered the works of McQuarrie & Krueger (2015) who recommended that the ideal size is between 5 and 8 per focus group. With this established, a total of 4 focus groups were conducted involving 21 construction professionals. The recruitment process involved selective sampling using inclusion criteria. As shown in table 1 the inclusion criteria specified that all participants had an active management position in the UK, previous experience using ImTs, a minimum of 5 years experience in construction and for participants to be aware of ImT applications for safety purposes.

Table 1 Participant Recruitment Criteria

The participants were allocated into groups containing a maximum of 6. The grouping of participants was designed to ensure each focus group had a range of roles, experience and included varied company sizes for a fair representation. Table 2 details the allocation and participant information including participant ID.

Table 2 Focus Group Allocation and Participant Information

The 4 online focus groups were conducted in March 2021 and moderated by the researcher (with experience in qualitative research, the use of ImTs and over 20 years within the construction industry). Each session had a duration of approximately 60 minutes. Initially participants were asked to provide a background of their role, organisation and frequency of using ImTs (including if these were used specifically for on-site safety applications) followed by 3 pre-written open questions (Hennink et al., 2019) which were shared on screen by the researcher (written in English language). These questions were designed to investigate the integration of ImTs, specifically for on-site safety purposes and included:

1) How is / could immersive technology be used within on-site construction safety processes?

2) What are / could be the significant impacts of using immersive technology in relation to site safety processes?

3) What are / could be the challenges of integrating immersive technology within on-site construction safety processes?

With each question maintained on screen, the construction professionals were asked to discuss and share their experiences. This method allowed for group discussions to be open and free-flowing whilst providing opportunities for participants and the researcher to pose further questions. The interactions were recorded via an online conferencing platform and the verbal discussions were transcribed manually for an accurate account.

Thematic Analysis

This study adopted thematic analysis, which can use an deductive or inductive approach. Deductive is 'top down' and is driven by theoretical interests. In contrast, an inductive form of analysis is 'bottom up' and driven by the data, therefore does not try to fit into a pre-existing coding structure (Braun & Clarke, 2006; Zulu & Khosrowshahi, 2021). Due to the limited theoretical underpinning within this specific field, an inductive approach was selected. In order to analyse the data consistently, this study followed the 6 phase framework developed by Braun and Clarke (2006).

Transcription and Familiarisation

The transcription and familiarisation process referred to phase 1 in Braun and Clarkes framework. To become familiar with the data, the transcription was completed manually by listening to the audio and typing verbatim. The transcription process ensured to take into account punctuation within the text and anonymised participants using their allocated participant ID. Any projects, companies or individuals were also anonymised during this process. Once the transcriptions were complete, they were uploaded into NVivo12, along with any informal notes. Within NVivo12, several read throughs of the transcripts were completed with the researcher adding informal 'memos' to areas of interest which acted as an aide-memoire during the later analysis phases (Braun & Clarke, 2021; Lochmiller, 2021). The researcher found these prior reading processes to be essential before coding began, to allow for deeper understanding of the data (Alhojailan & Ibrahim, 2012; Lochmiller, 2021).

Inductive Coding Process

Following phase 2 in Braun and Clarkes framework, the coding process systematically identified features of the data within the transcripts. Codes were assigned to passages of text including key phrases, sentences or paragraphs (Castleberry & Nolen, 2018). For this process NVivo12 was utilised. To begin the initial coding, each transcript was read whilst text was highlighted and assigned to codes that linked to its meaning (created by the researcher). In some cases, passages of text were assigned to multiple codes. As the data was assigned to codes, NVivo12 logged their code location and frequency. The initial coding process took two passes of the data sets and identified a total of 192 codes throughout all 4 transcripts.

Searching, Reviewing and Defining Themes

With the initial coding process complete, the researcher commenced with phases 3,4 and 5 of Braun and Clarkes framework. The codes were first sorted into broader themes. The process began with providing an outline description of each code and looked for commonality in the code name and description. The searching process involved the creation of theme maps, focusing on the relationships between the codes and to develop a structure of the codes and themes (Braun & Clarke, 2006). Due to the quantity of codes and themes, the researcher also introduced sub-themes. The extracts within the sub-themes were then reviewed and checked, this process resulted in numerous revisions to the theme names and the allocation of coding levels within the themes. Finally, each theme was analysed in descriptive text, what this represents and how it is linked to the research aim. This final process assisted the researcher in understanding the theme and how it would be presented within the results (phase 6).

Results

ImTs Integration for Safety Applications

The results from the initial discussion show that of the 21 active construction professionals, 19 identified that whilst they had used ImTs on projects this was rare, the remaining 2 stated they used ImTs often (both from large organisations). With specific regards to on-site safety applications, the results show that 1 participant used it often for this purpose. Of the 9 that indicated that it was rarely used for safety, 5 of these were large-sized organisations. 11 of the 21 professionals had never used this technology for any form of on-site safety application, and of these 8 worked within SMEs.

As identified, this study followed an inductive thematic analysis framework. The analysis of transcripts resulted in 3 key themes, 1) Drivers and Rationale 2) Implementation Challenges and 3) Establishing Impact. Within these 3 themes contained 12 sub-themes, that were derived from a total of 68 tier 2 codes and 35 tier 1 codes. Table 3 details the coding framework and lists themes, sub-themes and codes, including the number of references from the transcripts.

Table 3 Themes and Codes

The results of this study are presented by introducing the theme, followed by a narrative of the sub-theme and uses example extracts from the focus groups to support the findings.

Theme 1: Drivers and Rationale

During the analysis, codes were assigned to the data where the construction professionals spoke of the rationale for implementing ImTs within their site safety processes. Within the theme ‘drivers and rationale’ 3 sub-themes were allocated that derived from 9 tier 1 codes and 17 tier 2 codes.

Sub-Theme 1.1: Embracing Technology

Construction professionals felt strongly about the need to ‘embrace technology’ and described the importance of using technology to advance means of communication within their existing safety processes. Whilst many felt that the industry has progressed in its use of digital technology, they suggested it is still behind most other industries. They acknowledged that the use of technology is becoming ever more essential to increasing efficiency and improving safety on site. Participants also thought this of ImTs, for example, FG2 P4 who stated

> “*it is inevitable that the industry will have to embrace this sort of technology, companies who don’t go obsolete. So whether we like it or not it will be the way forward, times change and new technology will have to be adopted.*”

Participants who are rarely using ImTs and not specifically for safety applications showed enthusiasm and could see benefits within inductions, safety training and workshops. For instance, FG2 P3 commented, "*I think there is a place for immersive technology, I am right behind it and it is going to reduce risk and help protect people. It is about embracing new technology*". The construction professionals identified various challenges to embracing technology, with many suggesting it will take time for the use of ImTs to become commonplace on sites. This view was most apparent for those who worked for SMEs, for example, FG1 P1 noted "*To look at the 3D model in a headset is really useful, but I would say that would be more common in 10 years.*"

Sub-Theme 1.2: Supply Chain Innovation

The theme 'supply chain innovation' contained codes related to the independent uptake of ImTs within construction organisations. Some participants insisted that contractors are progressive in regard to their safety practices due to the importance of safety and do not need mandated requirements. For example, FG1 P1 commented:

> "*It's new technology* [ImTs] *and they* [contractors] *would lead on it more so than the client or any mandatory requirement because contractors want to reduce accidents, they want to try new ways of construction.*"

Participant FG2 P4 identified potential benefits in tendering, commenting that their clients are often looking for contractors who are using pioneering methods and developing safe systems of work, stating, "*in many ways the clients rely on that kind of innovation.*" Other participants provided further context from their own experiences and explained that the benefits would depend on how it was implemented and how it is received by their supply chain. Many clarified that the integration and engagement would need to be driven by senior management within the wider supply chain, which was found to be a potential challenge, particularly reported by SMEs.

Sub-Theme 1.3: Mandates and Regulation

Whilst some participants claimed that contractors should independently adopt technology, others felt that further integration of ImTs would require stipulation from their clients, or through 'mandates and regulations'. It was noted that this view mostly came from professionals working for smaller organisations. For example, FG1 P2 commented, "*I think a lot of times when you see implementation of new technology or new ways of doing things in construction, its led by governments and regulation.*" The need for clients to take an active role in their duties under Construction Design Management Regulations (CDM) 2015 was discussed by participants. FG4 P3 suggested that in requesting the use of ImTs on site, it could show their commitment to safety by providing methods aimed to surpass legislative requirements, noting:

> "*the clients have responsibility for health and safety… it's probably a reason for having immersive technology, it can prove that you have done way above and beyond what you can do to ensure safety.*"

Whilst this was seen as a key driver for the implementation of ImTs, many professed that their clients are not asking for them. Participants also spoke of the need to consider PAS1192-6:2018, which is assisting to drive technology use within their safety processes, however, indicated that ImTs are not specifically stipulated and is not a requirement. In addition, the mandated COVID restrictions requiring remote working were explored by many participants.

Most claimed that general technology awareness and use has increased considerably during government lockdowns, with many new technologies and processes adopted in their organisations at a quick pace. Whilst FG3 P3 indicated that their company had rarely used ImTs, they provided an example of increased interest.

> "*We saw a greater uptake in that* [immersive technology], *certainly during the COVID period where the guys are limited in their exposure to site… there were a select few sites that used it* [immersive technology] *during the COVID period and now we are coming out of the other side we are considering adopting it throughout all sites.*"

Theme 2: Implementation Challenges

Codes were assigned to data where professionals spoke of perceived challenges to the implementation of ImTs on their projects. The theme 'implementation challenges' contained 7 sub-themes generated from 17 tier 1 codes and 34 tier 2 codes.

Sub-Theme 2.1: Digital Expertise

Construction professionals described their thoughts on the current level of 'digital expertise' in the industry regarding ImTs. The responses were often short, for example, FG3 P5 simply stated "*There are not enough skills.*" Most felt there was an overall lack of expertise in ImTs, with one participant commenting:

> "*If the skills were there you would see it more. If it did not need specialist skills with a limited number of people who could implement this, I think this is what is holding it back. That and people's awareness.*" [FG1 P2]

As the extract identified, participant FG1 P2 felt these technologies were too specialist, and would require additional expertise to include these immersive environments within their existing site safety processes. Whilst some had the in-house expertise to manage this, one participant explained that when implementing ImTs for safety training they had to outsource expertise. In this example senior management questioned the need for additional roles and did not see the relevance to their organisation, stating "*we had to hire a games designer…but they were saying 'why do we need game designers? We are a construction company who pour concrete.'*" [FG3 P1]

FG3 P1 also indicated that if more clients requested the use of ImTs on their projects, senior management would naturally look to invest in this expertise, leading to an increase within the construction industry.

> "*Actually I don't think that skills are a barrier at all, it's the demand. If you had high demand then we would all be upskilling, we would all be on training courses, we would not need to be hiring outside of construction.*"

Sub-Theme 2.2: Is There a Demand for ImTs?

The theme 'is there a demand' consisted of codes related to internal and external demands for ImTs. Whilst many agreed construction companies should be driving the upskilling and implementation of ImTs, they also discussed the need for client demand or that its inclusion on projects would have to be accepted. For example, participant FG4 P3 argued:

> "*It has to be pushed from the top down. I mean the clients would have to pay for it at the end of the day, so they have to push to begin with. They have to be forward thinking, so its educating the clients out there.*"

The demand from clients was often linked to awareness, costs and culture. Some suggested that clients will not stipulate or accept the additional use of tools or processes that exceed requirements. To exemplify this, FG1 P2 stated:

> "*I think that a big part is the culture of the industry which is very much delivering projects. Clients are cost driven, if you have clients wanting the job done the cheapest way possible they will not want to be paying a premium for technology which they see as non-essential.*"

Construction professionals were asked to expand on this to ascertain why these technologies are rarely stipulated on projects. Participant FG4 P3 suggested this could be due to non-progressive clients and a shortage of industry practice case studies to evidence its value, and noted:

> *"I have worked with clients who are definitely forward thinking and risk takers, but that is very rare in the building sector… because it's not standard industry practice it's really hard to communicate the value added to the client… I saw a massive buy in into VR because they actually got their hands on it, a fully finished and developed product. So it links back into education. It's hard when you are trying to prove something without the thing you need to prove it with.*"

Sub-Theme 2.3: Resistance to Change

The most common challenge that emerged centred around a 'resistance to change' which occurred in 85 instances. Within this theme, codes included industry digitisation, with participants highlighting their concerns that the construction industry is slow to adopt new technology or processes and is "*One of the worst industries for it*" [FG3 P3]. Many suggested resistant behaviour is a key factor that affects the commitment of organisations or site teams to try new tools or ways of working. In one focus group, participants described the resistance they experience when discussing introducing ImTs on their projects, resulting in a sardonic conversation aimed towards industry culture.

> FG3 P1: "*We should be more progressive but"*
> FG3 P6: "*We have always done it this way, we don't need the gismos*"
> FG3 P1: "*And we never have any accidents*"
> FG3 P6: "*And everything always goes to plan, we are always fine*"

FG4 P3 also discussed their experience and noted, "*If we were to try and inject immersive technology into site safety processes, we will always get that backlash from site teams 'this is how we have always done it."* Having implemented ImTs within safety workshops, FG2 P4 described a continued reluctance from users and commented *"generally, I'd say 1 in 3 people would actually use it."*

Sub-Theme 2.4: Need for Resources

Whilst discussing its practical implementation within site inductions and logistical planning workshops, issues were raised around 'the need for resources'. In most cases, participants were concerned around the level of available resources to create, manage and use these immersive environments. Comments included:

> "*It all comes down to cost… it's the cost, time and resources… it's the people to be able to manage it, to develop it, monitor it, to amend it. All of these people… who pays for them*?... *it would cost a fortune*" [FG1 P3]
> "*The margins in construction or at least the declared margins are just so poor, it's really difficult for people to put any other money into this kind of thing, but they should do because it's going to give them the competitive advantage. Some short sightedness there*" [FG3 P5]
> "*Try to roll out 30 headsets to one site, no client would ever pay for that*" [FG4 P3]

Challenges around resources were a common concern across all data sets. According to FG2 P1 these challenges are greater in smaller organisations, stating "*it's all well and good for big construction companies, but what about your small house builder? Even technology at basic levels is nowhere near what it should be*". This said, FG4 P1 explained that having the resources together on larger-scale projects is just as rare, and added:

> "*you need a 3D model, you need a decent computer, you need the immersive environment, you need expertise and if they all exist on your project then it does not matter if its small or not, this does not exist on most of the big projects.*"

Sub-Theme 2.5: On-site Practicality

The theme 'On-site practicality' included codes involving the practical application of ImTs on construction sites. Participants explained that construction sites are temporary working environments that often have limited space and connectivity. With this practicality in mind, FG3 P3 simply said "*I think it has a long way to go before it is widely adopted for safety on-site.*"
These practicality issues referred to common safety activities such as planning workshops and inductions, which would often take place within the site welfare arrangements. Many participants thought this would be unrealistic due to space limitations, with the number of personnel required in the room, and the need to maintain a safe area to move whilst wearing VR headsets. Similar practical issues were highlighted when using CAVEs (Cave Automatic Virtual Environments). Others discussed the practicality and the challenges of acquiring the volume of equipment needed to use them for these purposes. For example, FG4 P1 commented:

> "*The next challenge is doing this on mass, if you wanted to induct 30 workers ... are you going to have 30 headsets? So don't get me wrong I think it's really good but it's the practicalities around it.*"

Sub-Theme 2.6 Leadership and Commitment

Within the theme 'leadership and commitment' codes were assigned when participants discussed senior management awareness and investment into ImTs. Many participants explained that if organisations are to adopt, high-level buy-in and investment is required. However, according to FG3 P6 there is a *"Lack of management commitment, well… a lack of engagement or interest"*. FG3 P5 commented on the level of investment made by organisations within the industry, suggesting:

> "*It's about defining the purpose of it* [immersive technology] *and seeing it as an investment rather than a cost. I mean, how much do construction companies put into research and development? Nothing really.*"

Construction professionals often spoke of challenges when proposing the trial of new tools to senior management, suggesting that there is too much focus on the costs. Comments included:

> *"you have an idea and you say 'this could really save time, save lives' but they will just say 'how long is it going to take? How much is it going to cost?"* [FG4 P3]
> "*But isn't this the conversation we always have about better ways of working, it's not the skills that's the problem, it's the leadership and the understanding that the investment will get you there*" [FG3 P1]
> "*I guess the demand from the clients is the external influence and the lack of commitment is the internal influence*" [FG3 P6]

Sub-Theme 2.7 Perceptions of ImTs

The theme 'perception of ImTs' focused on the project teams individual views. Whilst not the opinion of all participants, some linked negative perceptions to age. Many comments identified that generations who have not grown up with ImTs would tend not to accept the need for it and are less likely to engage with its use. Example statements included:

> "*you are going to get negativity, often from the older generation. They are just not going to buy into technology."* [FG1 P3]
> "*not everyone jumps in because we are not the 'Minecraft generation' yet, are we? For kids they will be working in a world where its fine to put on headsets but there is still a culture barrier*" [FG3 P1]
> "*if we are talking about immersive technology, we need to think about certain age groups that might not be into it. To others that are brought up with this, its normal to them on a day-to-day basis.*" [FG2 P2]

From their experience, participants explained that its use tends to be for marketing purposes and not for practical safety applications on-site. Participants indicated this led to negative industry perception, example statements included:

> "*I have not worked in a company where they have really embraced virtual reality. I have only worked for companies who buy a headset and have a desktop computer to run it but it was more of a gimmick and did not find a useful way of using it.*" [FG4 P2]
> "*We have used it as a bit of a 'gimmick' almost in career fairs to show our tech savviness"* [FG3 P3]
> "*The perception is that it's a gimmick… it's about defining purpose, to me VR needs that purpose defining, it ties into why people see it as a gimmick*" [FG3 P6]
> "*it was a bit of a gimmick to engage with the client, it was more of a sales pitch than actually a tool that was used for anything practical*" [FG1 P2]
> "*it's certainly seen as a toy and not to be taken seriously*" [FG4 P4]

Theme 3: Establishing Impact

Codes were assigned to data as participants spoke of the 'impact' of implementing ImTs within their on-site safety processes. This theme included 4 sub-themes which were derived from 9 tier 1 codes and 17 tier 2 codes.

Sub-Theme 3.1 Communication of Safety

'Communication of safety' incorporated codes related to conveying information within the project environment. Participants identified that from their experience, using ImTs is an effective method of visualising and retaining information. Due to the nature of complex logistics and temporary works planning, participants agreed the use of ImTs would be effective in developing risk assessments. FG4 P3 also noted the benefits of supply chain involvement, stating "*it would force the conversations to happen*". Many also stated that the use of ImTs improves upon traditional means of communicating information and linked this to its potential gains in safety workshops and inductions. Construction professionals also stated that these environments provide opportunities for feedback from the project team, supporting collaboration. When discussing this specifically around safety risk mitigation, FG4 P1 commented:

> "*the impact for me is positive… I think anyone discussing safety way in advance is a good thing. But its making it engaging that is the challenge… but without question it* [immersive technology] *can only improve it* [safety performance]."

Sub-Theme 3.2 Engagement and Collaboration

The theme 'Engagement and collaboration' combined codes related to team working environments and the engagement of the project team. Many construction professionals reported potential positive impacts when using ImTs for project collaboration. For instance, FG2 P1 claimed, "*it could be a collaborative process… rather than a one-to-one basis its getting all the trades together, putting in their input… that could really help to identify risks.*" Participants agreed that early-stage collaboration is an effective way to reduce safety risks, yet some doubted the current engagement and commitment of their wider project teams. Specifically the fulfilment of client roles and the mitigation of foreseeable risks in design, "*Do clients comply with CDM regulations and the preconstruction information? Probably not*" [FG2 P3]. Participant FG1 P2, highlighted how the use of ImTs could facilitate collaboration and improve engagement and noted "*this* [immersive technology] *could really improve engaging the principal designers with safety. At present I find they can be fairly detached from that role".* Participants also spoke of the engagement of contractors, highlighting that their involvement is often too late. Participant FG4 P6 described their experience.

> "*the key point has been in the installation side, but when the crew get involved they might not necessarily have been part of the design from the very beginning, so that then throws up questions to our design team as to 'how do you actually expect us to install this on site?'. The great thing is that with this* [immersive technology] *there's an opportunity to pick it up early on as opposed to them getting on site, getting a drawing out the van and saying 'there has been no thought here at all.'*"

Whilst participants discussed the benefits of using ImTs to engage the site team, FG3 P6 identified that this would also require facilitation and involvement from the site management, noting:

"*if it's a VR headset sat in a corner and you expect people to go and use it to check something – probably not. But if you are doing an induction or having a workshop or working through what your method of work is going to be and you are facilitating that, either taking people through an individual VR scenario or in a group where they don't necessarily have to do the driving, then I think you would get more people engaging than leaving it in the corner as a novelty.*"

Sub-Theme 3.3 Behaviour and Culture

The theme 'behaviour and culture' included codes describing safety attitudes, values and awareness. A follow-up question was asked whether safety behaviour and culture could be affected by the use of ImTs. Whilst some were sceptical of this impact, one participant who often uses ImTs specifically for safety training reported on its potential to impact behaviour, mainly in safety awareness, stating:

"*Safety behaviour yes, it will be impacted by the use of immersive technology… I think they* [operatives] *would be more alert on-site, they will be more careful. They will know where to look for the hazards and how to avoid them.*" [FG3 P4]

Many questioned existing methods of risk assessment and training, expressing the need for a more collaborative approach. Participants discussed how using ImTs within their existing processes could have an impact on the wider safety culture. For example, FG3 P6 commented:

"*I think if a company invests in implementing these technologies properly then it would promote the kind of environment where people have to ask questions… because it's about questioning, and if people are used to questioning in a site cabin with a headset on, then that should promote them to question when they are out on site.*"

Whilst the discussions around safety behaviour mainly focused on the positive impacts, some had concerns that overexposure to virtual simulations could lead to complacency, "*I think for me we need to be very careful with the technology, that it does not make us over complacent, that we become reliant on it*" [FG2 P3]. This concern tended to focus from a training context, particularly for those who may have low levels of site experience.

Sub-Theme 3.4 Risk Management

Participants discussed their experiences of using ImTs for 'risk management' specifically during the design, planning and construction stages. Some described improvements in the identification of hazards and the communication of foreseeable risks when integrating ImTs. For example, FG2 P1 noted:

"*Well if you just take the CDM regulations for example, you can use this in the pre-construction phase. You can walk around the design and can see it in the immersive world, you can spot issues that perhaps you would not spot until you were on site – that could save lives.*"

Whilst most participants shared similar views on the effectiveness of ImTs at early stages, some participants questioned its use during the construction phase. When planning site activities, some doubted how accurate this imitation would be in an immersive virtual world. For instance, FG1 P1 commented:

> "*Many accidents are caused through moving machinery, and I am not convinced that all this detail can be in the VR model… I can see it useful for the build, seeing the steelwork for example and the different interfaces. It would need to also show the equipment that people are using because without that a lot of the risks would be there but not shown in the model… to have a full environment that acts like a real site is almost impossible.*"

This said, participants spoke of using ImTs for safety workshops, inductions and developing risk assessments during the construction stage. When asked to further elaborate, participants explained that it was difficult to quantify the benefit, although agreed that using ImTs alongside the conventional methods generally led to increased engagement and improved communication.

Discussion

Whilst the data suggests that the use of ImTs can provide benefits for site safety management, like Khan et al. (2021) and Delgado et al. (2020), this study found that the implementation of ImTs in practice was low and rarely integrated within on-site safety processes. Although there appeared to be a relationship between the size of the organisation and the frequency of using ImTs on projects, this was not consistent as many larger organisations were rarely using these technologies. The data supports the previously identified impacts of ImTs when used within safety processes, such as improved communication (Khan et al., 2021) engagement (Bhoir & Esmaeili, 2015) and hazard awareness (Afzal & Shafiq, 2021) specifically when used in safety training, workshops and logistic planning exercises (Getuli et al., 2018). Whilst these similarities were reported, the results further this understanding in a number of areas. Firstly, the data in this study implies the implementation of ImTs has the potential to positively impact safety behaviour, and the wider organisational safety culture (Zhao & Lucas, 2014). Specifically, providing virtual collaborative environments to promote inclusion and a culture where further questions and concerns can be raised outside of the virtual space. Secondly the data suggests a potential long term negative safety impact, and links the use of ImTs to the thoughts of Oswald et al. (2014) who suggested over confidence can lead to complacency. Although some researchers have discussed the potential for virtual environments to unconsciously influence routine behaviours (Zhao & Lucas, 2014), few have highlighted concerns that virtual simulations of work tasks could lead to complacency in the real world, particularly for those with limited site experience.

The data implies that limited resources to create and manage such immersive environments are key contributing factors to the implementation of ImTs (Ghobadi & Sepasgozar, 2020), particularly on smaller projects. This study's findings indicate deeper concerns related to the adoption of ImTs. This included senior management investment, limited skills (Alizadehsalehi et al., 2021), on-site practicalities and resistant cultures. Prabhakaran et al. (2022) identified the need for skills and expertise in ImTs. The participants in this study also claimed that this expertise is rarely found from within the industry, and would often need to be outsourced from other industries to implement ImTs on-site. Participants indicated that further awareness and interest from senior management could see an increase in demand for ImTs, suggesting this would also lead to upskilling within the industry to meet these needs. The value of ImTs for clients, contractors and designers was also indicated by participants, as it was suggested that if applied within site safety planning this could support the fulfilment of duties under CDM 2015. Although many construction professionals agreed, others suggested that compliance can be demonstrated using more traditional methods and senior management would need convincing of its added value.

The question of who should lead and fund the use of ImTs was a key debate in this study. It was suggested by the construction professionals that this drive should be from progressive contractors who want to improve their safety processes and performance. However, others felt that client stipulation was essential to the integration of ImTs (Delgado et al., 2020). The participants in this study indicated that their clients are mostly uninterested in ImTs on their projects, and do not ask for them to be implemented. Interestingly this frustrated many of the professionals who suggested there are benefits of integrating ImTs, however claimed there is limited awareness, support or investment from their senior management or clients. Therefore implying that without client requirements for ImTs, the independent integration within the supply chain would be limited.

The construction professionals also described a reluctance from their site teams to accept these technologies (Fernandes et al., 2006) for common safety processes (such as inductions), claiming many would question why ImTs are needed within these processes. Many linked this to the perception of ImTs being seen as a 'gimmick' within the industry, indicating it would be a challenge for site teams to take them seriously. Providing sufficient tangible evidence to support the value of ImTs in order to justify its use was reported as a key challenge in this study. Like the findings of Delgado et al. (2020), professionals in this study suggested that senior management would rarely invest in technology without example cases that demonstrate its value, which participants claimed are not readily accessible. As with popular theories, such as Everett Roger's innovation diffusion theory, the perception of the technology is dependent on social aspects (Sartipi, 2020). In this study it was suggested that while there is an industry awareness of ImTs and safety applications, organisations are sceptical and are unlikely to adopt these technologies without solid evidence of their effectiveness, contributing to its continued low industry integration.

Contributions and Study Implications

This research builds on previous studies related to the adoption of ImTs and provides a fresh, industry-based insight into its application from a safety context. The contributions of this study are twofold. Firstly, the methodological approach presents real life practical experiences from active construction professionals, supporting industry awareness of ImTs and to encourage its use within on-site safety applications. Secondly the paper identifies industry based contributing factors influencing the integration of ImTs within on site safety processes.

The results of this study suggest that the integration of ImTs can be influential in improving communication, collaboration and risk assessment. However its low adoption on site stems from multiple areas, including the technological limitations, resources and behavioural challenges. Managers and clients who have influence in the practical implementation of technologies can be informed through this study. For example, the findings of this research can be considered to inform decisions and reduce disruption during future on-site implementation, or to enhance the effectiveness of existing applications. Other researchers could develop this field further by using these findings as an instrument for further qualitative studies. For instance, testing these influencing factors within active construction projects trialling the use of ImTs within on-site safety processes or to develop strategies to assist with industry implementation.

Conclusion

This paper aimed to investigate contributing factors influencing on-site implementation of ImTs, specifically from a safety context. Adopting a qualitative approach and using inductive thematic analysis, this study presented in-depth accounts from experienced construction professionals. The study found a total of 12 sub-themes which were developed from 68 tier 2 codes and 35 tier 1 codes. The data indicated that contributing driving factors focused on a desire to demonstrate a commitment to safety and digitise safety processes. Construction professionals indicated that whilst using ImTs could make improvements in communication of hazards and engagement within on-site safety processes, the application of ImTs on site was rare. Investment from senior management into ImTs was seen as having the potential to improve organisational safety culture, encouraging participation and questioning from the site team. However, concerns were raised regarding the long-term use of ImTs, recognising the potential in developing over confidence and complacency. A need for specialist expertise in the technical creation and management of ImTs was identified as a core challenge in addition to perceived high costs, limited resources and the practicality of using ImTs in site environments. Whilst the limited demand for ImTs may not deter progressive organisations from integrating ImTs into their site safety processes, for others the challenges preventing its integration remain too great.

The researchers note the limitations in this study. A selective sampling approach was chosen that adopted an online recruitment campaign. However, specific recruitment criteria resulted in a limited number of participants engaging in the study who had used ImTs specifically for safety applications. Despite its limitations, this study opens the door for further research to build upon. Future empirical studies that aim to investigate the practical site integration of ImTs within safety processes that test these findings are encouraged.

Conflict of Interest Statement

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

References

Afzal, M. & Shafiq, M. T. (2021) Evaluating 4D-BIM and VR for Effective Safety Communication and Training: A Case Study of Multilingual Construction Job-Site Crew. *Buildings*, 11 (319), pp. 1–24.

Alhojailan, M. I. & Ibrahim, M. (2012) Thematic Analysis : A Critical Review of Its Process and Evaluation. *WEI International European AcademicConference Proceedings*, 1 (2011), pp. 8–21.

Alizadehsalehi, S., Hadavi, A. & Huang, J. C. (2021) Assessment of AEC Students' Performance Using BIM-into-VR. *Applied Sciences (Switzerland)*, 11 (7).

Babalola, A., Manu, P., Cheung, C., Yunusa-Kaltungo, A. & Bartolo, P. (2023) A Systematic Review of the Application of Immersive Technologies for Safety and Health Management in the Construction Sector. *Journal of Safety Research* [Online], (xxxx). Available from: <https://doi.org/10.1016/j.jsr.2023.01.007>.

Bhoir, S. & Esmaeili, B. (2015) State-of-the-Art Review of Virtual Reality Environment Applications in Construction Safety. *Architectural Engineering Institute* [Online], pp. 457–468. Available from: <https://ascelibrary.org/doi/abs/10.1061/9780784479070.040>.

Braun, V. & Clarke, V. (2006) Using Thematic Analysis in Psychology. *Applied Qualitative Research in Psychology*, 3 (2), pp. 77–101.

Braun, V. & Clarke, V. (2021) One Size Fits All? What Counts as Quality Practice in (Reflexive) Thematic Analysis? *Qualitative Research in Psychology* [Online], 18 (3), pp. 328–352. Available from: <https://doi.org/10.1080/14780887.2020.1769238>.

Castleberry, A. & Nolen, A. (2018) Thematic Analysis of Qualitative Research Data: Is It as Easy as It Sounds? *Currents in Pharmacy Teaching and Learning* [Online], 10 (6), pp. 807–815. Available from: <https://doi.org/10.1016/j.cptl.2018.03.019>.

Chun, C. K., Li, H. & Skitmore, R. M. (2012) The Use of Virtual Prototyping for Hazard Identification in the Early Design Stage. *Construction Innovation : Information, Process, Management*, 12 (1), pp. 29–42.

DelaCruz, O. G. & Dajac, J. S. (2021) Virtual Reality (VR): A Review on Its Application in Construction Safety. *Turkish Journal of Computer and Mathematics Education*, 12 (11), pp. 3379–3393.

Delgado, J., Oyedele, L., Beach, T. & Demian, P. (2020) Augmented and Virtual Reality in Construction Drivers and Limitations for Industry Adoption. *Journal of Construction Engineering and Management*, 146 (7), pp. 1–35.

ElGewely, M. & Nadim, W. (2020) Immersive Virtual Reality Environment for Construction Detailing Education Using Building Information Modeling (BIM). *Lecture Notes in Mechanical Engineering*, (September), pp. 101–112.

Farmer, M. (2016) *The Farmer Review of the UK Construction Labour Model*. Construction Leadership Council.

Fernandes, K. J., Raja, V., White, A. & Tsinopoulos, C. D. (2006) Adoption of Virtual Reality within Construction Processes: A Factor Analysis Approach. *Technovation* [Online], 26 (1), pp. 111–120. Available from: <https://www.sciencedirect.com/science/article/abs/pii/S0166497204001270>.

Froehlich, M. & Azhar, S. (2016) Investigating Virtual Reality Headset Applications in Construction [Online]. In: *Proceedings of the 52nd ASC Annual International Conference*, *2016*. Available from: <http://ascpro.ascweb.org/chair/paper/CPRT195002016.pdf>.

Getuli, V., Giusti, T., Capone, P., Sorbi, T. & Bruttini, A. (2018) A Project Framework to Introduce Virtual Reality in Construction Health and Safety. *AlmaDL Journals, New Frontiers of Construction Management Workshop* [Online], 09 (13), pp. 166–175. Available from: <https://in_bo.unibo.it/article/view/8830/8950>.

Ghobadi, M. & Sepasgozar, S. (2020) An Investigation of Virtual Reality Technology Adoption in the Construction Industry. In: Shirowzhan, S. & Zhang, K. ed., *Smart Cities* *and Construction Technologies*. London, pp. 1–35.

Gibbs, A. (1997) Social Research Update 19: Focus Groups [Online]. University of Surrey: Department of Sociology. Available from: <http://sru.soc.surrey.ac.uk/SRU19.html>.

Guest, G., Namey, E. & McKenna, K. (2017) How Many Focus Groups Are Enough? Building an Evidence Base for Nonprobability Sample Sizes. *Field Methods* [Online], 29 (1), pp. 3–22. Available from: <https://journals.sagepub.com/doi/abs/10.1177/1525822X16639015>.

Hamil, D. S. (2019) A Digital Future for the Construction Industry. *National Building Specification* [Online]. Available from: <https://www.thenbs.com/knowledge/A-Digital-Future-for-the-Construction-Industry>.

Hennink, M. M., Kaiser, B. N. & Weber, M. B. (2019) What Influences Saturation? Estimating Sample Sizes in Focus Group Research. *Qualitative Health Research*, 29 (10), pp. 1483–1496.

HSE (2022) *Construction Statistics in Great Britain, 2022* [Online]. Available from: <https://www.hse.gov.uk/statistics/industry/construction.pdf>.

Khan, A., Sepasgozar, S., Liu, T. & Yu, R. (2021) Integration of Bim and Immersive Technologies for Aec: A Scientometric-swot Analysis and Critical Content Review. *Buildings*, 11 (3), pp. 1–34.

Li, H., Chan, G. & Skitmore, M. (2012) Multiuser Virtual Safety Training System for Tower Crane Dismantlement. *Journal of Computing in Civil Engineering*, 26 (5), pp. 638–647.

Lobe, B., Morgan, D. & Hoffman, K. A. (2020) Qualitative Data Collection in an Era of Social Distancing. *International Journal of Qualitative Methods*, 19, pp. 1–8.

Lochmiller, C. R. (2021) Conducting Thematic Analysis with Qualitative Data. *Qualitative Report*, 26 (6), pp. 2029–2044.

McQuarrie, E. F. & Krueger, R. A. (2015) *Focus Groups: A Practical Guide for Applied Research*. London: Sage Publications.

Mohammadi, A., Tavakolan, M. & Khosravi, Y. (2018) Factors in Fluencing Safety Performance on Construction Projects : A Review. *Safety Science*, 109 (October 2016), pp. 382–397.

Muhammad, A. A., Yitmen, I., Alizadehsalehi, S. & Celik, T. (2020) Adoption of Virtual Reality (VR) for Site Layout Optimization of Construction Projects. *Teknik Dergi/Technical Journal of Turkish Chamber of Civil Engineers*, 31 (2), pp. 9833–9850.

Nyumba, T., Wilson, K., Derrick, C. J. & Mukherjee, N. (2018) The Use of Focus Group Discussion Methodology: Insights from Two Decades of Application in Conservation. *Methods in Ecology and Evolution*, 9 (1), pp. 20–32.

Okoro, C., Nnaji, C. & Adediran, A. (2022) Determinants of Immersive Technology Acceptance in the Construction Industry: Management Perspective. *Engineering, Construction and Architectural Management* [Online], ahead-of-p (ahead-of-print).

Available from: <https://doi.org/10.1108/ECAM-06-2021-0476>.

Olugboyega, O. & Windapo, A. (2019) Building Information Modeling—Enabled Construction Safety Culture and Maturity Model: A Grounded Theory Approach. *Frontiers in Built Environment*, 5 (April), pp. 1–12.

Oswald, D., Sherratt, F. & Smith, S. (2014) Risk Perception and Safety Behaviour: An Ethnograpic Study [Online]. In: *Proceedimgs of CIB W099 Achieving Sustainable Construction Health and Safety*, *2014*. pp. 2–12. Available from: <https://www.researchgate.net/profile/Hamza_Gabriel/publication/275037120_Investigation_of_fall_protection_practices_in_the_construction_industry_of_Pakistan/links/554310940cf234bdb21a309a.pdf#page=599>.

Perlman, A., Sacks, R. & Barak, R. (2014) Hazard Recognition and Risk Perception in Construction. *Safety Science* [Online], 64, pp. 22–31. Available from: <https://www.sciencedirect.com/science/article/pii/S0925753513002877>.

Prabhakaran, A., Mahamadu, A. M. & Mahdjoubi, L. (2022) Understanding the Challenges of Immersive Technology Use in the Architecture and Construction Industry: A Systematic Review. *Automation in Construction* [Online], 137 (January), p. 104228. Available from: <https://doi.org/10.1016/j.autcon.2022.104228>.

Sacks, R., Perlman, A. & Barak, R. (2013) Construction Safety Training Using Immersive Virtual Reality. *Construction Management and Economics* [Online], 31 (9), pp. 1005–1017. Available from: <https://www.tandfonline.com/doi/full/10.1080/01446193.2013.828844?scroll=top&needAccess=true>.

Sacks, R., Whyte, J., Swissa, D., Raviv, G., Zhou, W. & Shapira, A. (2015) Safety by Design : Dialogues between Designers and Builders Using Virtual Reality. *Construction Management and Economics* [Online], 33 (1), pp. 55–72. Available from: <http://dx.doi.org/10.1080/01446193.2015.1029504>.

Sartipi, F. (2020) Diffusion of Innovation Theory in the Realm of Environmental Construction. *Journal of Construction Materials*, 1 (4).

Smith, D. (2020) Looking Into the Future of Virtual and Augmented Reality in Construction. *Construction excutive* [Online]. Available from: <https://www.constructionexec.com/article/looking-into-the-future-of-virtual-and-augmented-reality-in-construction>.

Suh, A. & Prophet, J. (2018) The State of Immersive Technology Research: A Literature Analysis. *Computers in Human Behavior* [Online], 86, pp. 77–90. Available from: <https://doi.org/10.1016/j.chb.2018.04.019>.

Swallow, M. & Zulu, S. (2020a) Impacting Construction Health and Safety Performance Using Virtual Reality - A Scoping Study Review. In: *Proceedings of the Joint CIB W099 & TG59 International Web-Conference 2020: Good Health, Wellbeing & Decent Work*, *2020*. pp. 132–143.

Swallow, M. & Zulu, S. (2020b) Virtual Reality in Construction Health and Safety Education: Students Experience Through Video Elicitation - A Pilot Study. In:

Proceedings of 20th International Conference on Construction Applications of Virtual Reality, *2020*. Middlesbrough, pp. 86–94.

Zhao, D. & Lucas, J. (2014) Virtual Reality Simulation for Construction Safety Promotion. *International Journal of Injury Control and Safety Promotion* [Online], 22 (1), pp. 57–67. Available from: <https://www.tandfonline.com/doi/abs/10.1080/17457300.2013.861853>.

Zulu, S. L. & Khosrowshahi, F. (2021) A Taxonomy of Digital Leadership in the Construction Industry. *Construction Management and Economics* [Online], 39 (7), pp. 565–578. Available from: <https://doi.org/10.1080/01446193.2021.1930080>.

Description	***Focus groups selection criteria***
Size of organisation	Any size
Type of work	New build construction, refurbishment, demolition
BIM adoption within organisation	Essential
Participant in management / professional role	Essential
Participant years of industry experience	5 years +
Participant currently / previously used ImTs	Essential
Participant aware of ImTs for safety purposes	Essential

	No	Participant ID	Participant Role	Country of work	Age range	Years in industry	Category of company size	Previous / currently experience using ImTs?	Aware of ImTs for safety Applications
Focus group 1	1	FG1 P1	Contracts Manager	UK	31-39	21-30	SME	Yes	Yes
	2	FG1 P2	Commercial Manager	UK	31-39	11-20	SME	Yes	Yes
	3	FG1 P3	Contracts Manager	UK	31-39	21-30	SME	Yes	Yes
	4	FG1 P4	Commercial Manager	UK	31-39	11-20	SME	Yes	Yes
	5	FG1 P5	Company Director	UK	31-39	11-20	SME	Yes	Yes
Focus group 2	6	FG2 P1	Architect	UK	50+	31-40	SME	Yes	Yes
	7	FG2 P2	Project Manager	UK	18-30	5-10	SME	Yes	Yes
	8	FG2 P3	Project Manager	UK	50+	31-40	Large	Yes	Yes
	9	FG2 P4	Civil Engineer	UK	31-39	21-30	Large	Yes	Yes
Focus group 3	10	FG3 P1	4D Planning / Manager	UK	31-39	21-30	SME	Yes	Yes
	11	FG3 P2	4D Planning / Manager	UK	31-39	5-10	SME	Yes	Yes
	12	FG3 P3	Innovation Manager	UK	18-30	5-10	Large	Yes	Yes
	13	FG3 P4	BIM Manager	UK	31-39	5-10	Large	Yes	Yes
	14	FG3 P5	Director / Project Planner	UK	31-39	11-20	SME	Yes	Yes
	15	FG3 P6	4D Planner Consultant	UK	31-39	5-10	SME	Yes	Yes
Focus group 4	16	FG4 P1	Digital Manager	UK	31-39	11-20	Large	Yes	Yes
	17	FG4 P2	Structural Engineer	UK	31-39	5-10	SME	Yes	Yes
	18	FG4 P3	Visualisation Specialist	UK	31-39	5-10	Large	Yes	Yes
	19	FG4 P4	Digital Manager	UK	31-39	21-30	Large	Yes	Yes
	20	FG4 P5	4D Planning Manager	UK	31-39	5-10	Large	Yes	Yes
	21	FG4 P6	Digital Manager	UK	31-39	11-20	Large	Yes	Yes

Theme	*Sub-Theme*	*Tier 1 code*	*Tier 2 code*	*Total Number of references*
Theme 1 – Drivers and Rationale	**1.1** Embracing technology	**1.1.1** Drive to innovate in construction	**1.1.1.1** Need and demand for technology on site	18
		1.1.2 Developing collaboration	**1.1.2.1** Collaborative tools in safety processes	
		1.1.3 Developing new roles	**1.1.3.1** Technical skills in construction	
	1.2 Supply chain innovation	**1.2.1** Contractor benefits	**1.2.1.1** Marketing applications	22
			1.2.1.2 Accident reduction on site	
			1.2.1.3 Improving safety strategy	
			1.2.1.4 Improved safety planning	
		1.2.2 Independent contractor driven	**1.2.2.1** Going alone to adopt ImTs	
			1.2.2.2 Clear leadership	
		1.2.3 Importance of safety	**1.2.3.1** Corporate safety image	
	1.3 Mandates and regulations	**1.3.1** PAS 1192-6 requirements	**1.3.1.1** No specific identification of ImTs	11
			1.3.1.2 Encouragement of technology for safety	
		1.3.2 CDM 2015 requirements	**1.3.2.1** Contractor planning duties	
		1.3.3 COVID lockdown restrictions	**1.3.3.1** use of ImTs in remote working	
			1.3.3.2 Increased adoption of ImTs	
			1.3.3.3 Continued use of ImTs on site	
			1.3.3.4 Online inductions using ImTs	
Theme 2 – Implementation Challenges	**2.1** Digital expertise	**2.1.1** Skills	**2.1.1.1** Industry 'non tech' users	28
			2.1.1.2 Unneeded complexity	
			2.1.1.3 Led to complacency?	
		2.1.2 Knowledge	**2.1.2.1** Other industries skills required	
			2.1.2.2 Need for digital skills	
	2.2 Is there a need for ImTs?	**2.2.1** Size and scale	**2.2.1.1** Project are too small	42
			2.2.1.2 Size of company	
		2.2.2 On site need?	**2.2.2.1** lack of Client demand	
			2.2.2.2 Lack of demonstrated benefits	
		2.2.3 Need for leadership	**2.2.3.1** Having an active role in safety processes	
	2.3 Resistance to change	**2.3.1** Industry digitisation	**2.3.1.1** A lack of technical skills	85
			2.3.1.2 An 'old fashioned industry'	
			2.3.1.3 Fear of change	
		2.3.2 Culture and behaviour	**2.3.2.1** Relaying on technology	
			2.3.2.2 Don't want to use ImTs	
			2.3.2.3 A need for real life risk	
	2.4 Resources to Implement	**2.4.1** Resources to update	**2.4.1.1** Who is to update the VR model?	32

		2.4.2 Time and resources	**2.4.2.1** Too much time to use	
		2.4.3 Cost to implement	**2.4.3.1** Cost driven clients	
			2.4.3.2 No money on the project for innovation	
			2.4.3.3 Is there return value?	
	2.5 On site practicality	**2.5.1** Technological challenges	**2.5.1.1** Overselling software vendors	19
			2.5.1.2 Fast moving technology	
			2.5.1.3 Environment realism	
		2.5.2 Limitations of ImTs	**2.5.2.1** Isolating within headsets	
			2.5.2.2 Sensory limitations	
	2.6 leadership and commitment	**2.6.1** Senior management engagement	**2.6.1.1** Senior managers aware of benefits?	32
			2.6.1.2 A need for digital leadership	
		2.6.2 Investment in technology	**2.6.2.1** High level buy in	
		2.6.3 Industry awareness of ImTs	**2.6.3.1** ImTs purpose in safety clear?	
			2.6.3.2 Difficult to measure safety performance impact	
	2.7 Perceptions of ImTs	**2.7.1** Demographic	**2.7.1.1** Age of users	41
			2.7.1.2 Gender of users	
		2.7.2 Perception as a gimmick	**2.7.2.1** Confidence in ImT benefits on site	
Theme 3 – Establishing Impact	**3.1** Communication of risk	**3.1.1** Reducing miscommunication	**3.1.1.1** Overcoming language barriers	14
			3.1.1.2 Improved visual of hazards	
		3.1.2 Communication of hazard and controls	**3.1.2.1** Feedback from the site team	
			3.1.2.2 Communicating from off site to site	
	3.2 Engagement and collaboration	**3.2.1** Project team collaboration	**3.2.1.1** Involving the site team	27
			3.2.1.2 Detached design team from site	
			3.2.1.3 Client engagement with safety concerns	
		3.2.2 Site team safety engagement	**3.2.2.1** Safety workshop / induction engagement	
			3.2.2.2 Integrating site experience	
	3.3 Safety Culture / behaviour	**3.3.1** Safety awareness	**3.3.1.1** Effective retention	24
		3.3.2 Individual safety behaviour	**3.3.2.1** Increasing complacency	
			3.3.2.2 Taking ownership of safety	
	3.4 Risk mitigation	**3.4.1** Interactive safety workshops	**3.4.1.1** Improvements to workshops and inductions	28
			3.4.1.2 Virtual rehearsals	
		3.4.2 Designing out risk	**3.4.2.1** Immersive planning and risk assessment	
		3.4.3 Hazard identification processes	**3.4.3.1** Virtual risk assessment	
			3.4.3.2 Accuracy of risk assessment	