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SWALLOW, Mark and ZULU, Sam

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Enhancing Collaboration and Engagement using Virtual Reality Within Site Safety Planning

Mark Swallow, MCIOB, Tech IOSH, BSc (Hons)
Department of Natural and Built Environment, Sheffield Hallam University, Sheffield, England

Sam Zulu, MCIOB, MRICS, SFHEA, PhD, MS, MSc
School of Built Environment, Engineering and Computing, Leeds Beckett University, Leeds, England

Mark Swallow
Sheffield Hallam University

m.swallow@shu.ac.uk

Abstract

For construction managers effective collaboration, communication and engagement during safety planning, is essential to improve on-site efficiency and reduce risks. Whilst the use of Virtual Reality (VR) has gained increased global attention in the past decade, the documentation of practical applications during active construction projects in the UK remains underdeveloped. Specifically, this includes the use of VR within on-site construction logistics management processes, and its potential impacts on multidisciplinary collaboration and engagement. This study aims to bridge this gap by exploring the use of VR during practical safety and plant logistics planning workshops to capture real-world examples. Collaborating with a UK based construction contractor, this study collected qualitative data over a series of planning workshops during a live project, involving 15 site team members of varying disciplines. Data collection included direct observations and focus groups, with data analysed using a hybrid thematic analysis method. The results provided evidence of effective and accurate plant logistics planning with working practical examples, indicating that the use of VR had a positive impact on interdisciplinary collaboration and engagement. Results show that the inclusion of VR tools also encouraged knowledge transfer between project teams, which led to improved confidence and engagement when conducting planning activities.

Keywords

Construction management, Health & safety, Logistics

1 Introduction

On-site safety and plant logistics planning requires co-ordination with a multitude of project disciplines, often involving numerous organisations with varied levels of knowledge, experience and awareness of the specific project design and site constraints. From a construction management perspective, collaboration and engagement within the planning process is crucial to the efficiency and safe execution of construction activities (Prabhakaran et al., 2022).

Whilst on-site safety planning has historically relied on 2D information, the construction industry has seen an increased uptake in digital technologies. For instance the use of 3D and 4D modelling have been shown to have practical benefits in safety and logistics planning, specifically in improving visualisation and communication (BSI, 2018; Swallow & Zulu, 2019). The application of immersive technologies (ImTs) including cave automatic virtual environments (CAVEs) and virtual reality (VR) are also receiving growing attention within the construction industry (Aflizadehsalehi et al., 2021). Within academia, many have begun to explore the effects of utilising VR technology for safety purposes, for example in engagement within safety training (Sacks et al., 2013; Vasilevski & Birt, 2020), knowledge retention (Feng et al., 2023) and hazard identification (Abotaleb et al., 2023). However despite the identified benefits in literature, the implementation of VR within the construction industry remains low (Delgado et al., 2020; Ghobadi & Sepasgozar, 2020; Okoro et al., 2022). According to the NBS (2023) only 36% of organisations use ImTs, mainly applying these tools for stakeholder walkthroughs and design visuals rather than on-site safety applications. The limited real-world project case studies investigating the effectiveness of VR for safety management has resulted in researchers calling for further exploration (Babalola et al., 2023; Swallow & Zulu, 2020), specifically involving the on-site construction management and operatives (DelaCruz & Dajac, 2021). To address these issues, this study aims to document practical accounts using VR within a live case project. This provides a fresh insight into the impacts on multidisciplinary collaboration and engagement during safety and plant logistics planning, from a site team perspective.

This study forms part of a wider research project into the drivers, applications, challenges and impacts of the practical implementation of ImTs within the context of on-site safety management. In this study qualitative data was collected through direct observations of safety and plant logistics workshops within a UK based construction project, followed by focus group discussions. Through applying hybrid thematic analysis, the results provide practical examples of the application of VR, furthering the research into the impact on multidisciplinary collaboration and engagement.

2 Virtual Reality within Construction Safety Planning

ImTs have taken significant strides in practical industry applications within recent decades. Whilst CAVEs have been applied within safety research (Perlman et al., 2014), developments in VR headset technology, led by the gaming industries, has resulted in mainstream awareness, affordability and increased practicality (Cipresso et al., 2018; Coburn et al., 2017; Lugrin et al., 2013; Pino, 2020; Stefan et al., 2023). Typically, VR uses a head mounted display (HMD) and hand controller devices, allowing the user to immerse and interact within a fully computer generated virtual world. The now portable VR applications offer a potential solution for the construction industry, providing opportunities for on-site safety applications such as interactive exploration, hazard identification (ElGewely & Nadim, 2020; Jeelani et al., 2017) and specific site safety training (Norris et al., 2019).

Whilst various challenges of VR headset applications have been identified within literature, such as cybersickness (Coburn et al., 2017; Khan et al., 2021; Weech et al., 2019) and user isolation (Swallow & Zulu, 2021), many researchers have indicated that VR has the ability to improve engagement (Peña & Ragan, 2017) and communication (Khan et al., 2021). Moreover, these technologies have been shown to be an effective medium to visualise and explore detailed designs or work sequences in advance to the build process. For example, Muhammad et al. (2020) compared the use of VR to traditional 2D forms of planning, finding a VR approach more effective in collision detection. Rolim et al. (2020) explored the use of VR for developing risk assessments within a Brazilian airport development by conducting an exploratory case study. Their results indicated improvements in the identification and evaluation of risk from an operation teams perspective. From a mechanical and electrical design review context, Zaker & Coloma (2018) investigated the application of VR using real models on a project in Barcelona, identifying practical benefits in clash detection applications. Afzal & Shafiq (2021) investigated the use of 4D VR on a project in United Arab Emirates to simulate construction activities. Their research assessed the impact on communication and risk assessment where project members did not share a common language, concluding that VR simulations increased hazard identification among operatives.

Whilst the benefits of ImTs within academia are acknowledged, practical on-site based applications of VR from a safety management and logistics planning context has received limited attention. Moreover, there is a dearth of research that focuses specifically on the impact on multidisciplinary collaboration and engagement from the perspective of active site teams. This paper seeks to explore these currently underdeveloped areas.

3 Methodology

Case studies are a common research strategy, that "*involves an in-depth examination and analysis of a particular phenomenon or case, such as an individual, organization, community, event, or situation*" (Hassan, 2022). A study of a case within its real life setting allows a phenomena to be explored within its context and environment, with flexibility in its design (Saunders et al., 2019). Yin (2003) suggests that case studies can adopt either qualitative or quantitative approaches and can be designed as exploratory, explanatory or descriptive. Moreover, they can be described as a single case study (used to understand one unique or extreme case), or multiple to allow comparisons between cases (Baxter et al., 2008). Exploratory case studies are suited to this research aim as they explore data in real-life and natural settings, including the complexities of these real situations. This is also a suitable approach where there is limited pre-existing knowledge in the specific field (Hassan, 2022).

3.1 The Sample

For this study the researchers selected a single case to produce in-depth data to understand this specific phenomenon in detail. The researchers collaborated with a UK-based construction contractor, selected through purposive sampling, who were looking to develop their existing 2D / paper-based safety workshop process to include the application of VR. The selected case project was the design and construction of a 3 storey new build extension to an existing (live) school located in England. For this paper, only the data collected which related to the steel frame and ground floor concrete installation are included, as these are common yet high risk site activities.

The participants involved in this study were working directly on the case project and site activity. A total of 15 site members contributed, consisting of 1 senior director, 4 project / site managers, 1 commercial manager, 3 quantity surveyors, 1 safety manager and 5 steel erection operatives (subcontractors). The site management and commercial management were familiar with the project, however the operatives had not been involved with the project to this point. Fig. 1 identifies the participants, their ID, role, age range and industry experience. Whilst the contractor had prior experience with VR, this was limited from a site perspective. From the 15 participants in this study, only 2 had prior experience and the remaining 13 had no experience using VR (including all of the project / site managers, quantity surveyors and site operatives).

Fig. 2 overviews the data collection methodology. Following the recruitment of the case organisation and collection of project information needed to create the VR environment, qualitative data was collected through observations during on-site workshops and subsequent focus groups. The data was then analysed using a hybrid thematic analysis method.

3.2 Safety and Plant Logistics Planning Workshops

The researchers provided VR headsets in place of 2D processes, which were used when planning their methods of safe installation, construction plant positioning / vehicle movement and segregation zones. Prior to conducting the practical workshops, researchers consulted with the construction contractor to evaluate the hardware / software requirements and project information to construct the VR environments accurately. During the time of the study the Meta Quest 2 headsets were introduced in the market, which were an affordable and easily accessible devise. It was decided these were to be used, as the headsets required no tripod sensor set up and so the most practical for on-site use. To run the VR models, laptop devices with Intel Core i7 processors were provided by the researchers which utilized Autodesk Revit software. In order to create the immersive environments, 2D and 3D project information was shared by the contractor from the project common data environment (CDE), allowing the researchers to integrate the information into central Revit site logistics models. Firstly, the surrounding site and existing structures were modelled from survey data taken by the researchers. Next the 3D steel superstructure model (received in IFC file format) was integrated into the Revit model to the precise orientation. General on-site arrangements (such as welfare and perimeter fencing) were modelled using the locations shown in 2D layout plans, and initial phasing markup drawings were used as reference for sequencing the steel frame. Lastly, typical plant and safety equipment were loaded into the central Revit logistics models, ready for use during the workshops.

The on-site data collection took place between December 2021 and April 2022 which included direct observations, focus groups and photo capture. Whilst the interactions were planned, the timescales for these were often influenced by the live on-site programme and the completion of site activities. The rationale for having various interactions was to capture participants views of the process, from planning of the activities through to the on-site installation works. Fig. 3 provides an example set up of the logistic planning workshops. Hardware equipment was set up within the on-site office facilities, with VR headsets and hand controllers provided to the site team and used by various participants. During the time of the data collection, additional COVID-19 safety precautions were also in place (including additional cleaning of equipment between use and optional PPE).

A total of 3 workshops related to the planning of the steel frame and concrete floor installation were observed, each were led by the project manager [CS PM1] and site manager [CS SM1] and took between 60 – 90 minutes to conduct. Due to the live project environment and multiple interaction points, the participants involvement was dependent on their availability, fig 4 identifies the participants within each workshop and subsequent focus group.

During the workshops the researchers did not participate, however did observe the interactions, taking notes and photographs (Hassan, 2022; Priya, 2021). During the logistics planning workshops, VR headset visuals were projected onto the wall screen and verbal discussions captured for accurate records.

3.3 Focus Group Discussions

Following each planning workshop the researchers (each with over 20 years' experience within the construction industry) facilitated a focus group discussion involving all of the participants present. Focus groups are a common method used for data collection in exploratory research and were designed as semi-structured in nature, conducted face to face within the site meeting room area. The overall purpose of the focus groups was to capture the site teams views on the use of VR within safety and plant logistics planning on-site, asking questions such as

"*Through your experience using immersive technology on this project, could this be impactful for safety management*?"

During the focus groups, the researchers included follow up questions more specifically related to impact factors, including multidisciplinary collaboration and engagement. Focus group discussions utilised Microsoft teams to record audio and visual, which assisted the researchers in accurately transcribing data sets involving multiple participants.

3.4 Hybrid Thematic Analysis

Hybrid thematic analysis involves both deductive (theory driven) and inductive (data driven) approaches (Swain, 2018). The analysis process began with transcribing the qualitative data, followed by a process of familiarisation, which also included reviewing photos and video footage from the workshops. Assisted by the use of NVivo12 software, key text and phrases within the transcripts were allocated into pre-existing codes, (a priori codes) developed by the researchers and published in 2023 (Swallow & Zulu, 2023). This coding book contained a total of 142 codes, categorised into 17 themes. Due to the aim of this study, the results focused on theme 15 - *engagement and collaboration*. As the analysis was hybrid in nature, the researchers also created new codes (a posteriori codes) if they were not present in the coding book (Swain, 2018). Once the initial coding was complete, theme maps where created that assisted in the refinement of codes within this theme. Fig. 5 provides an example of the key stages of the analysis process.

4 Results

The theme *engagement and collaboration* was referenced on 61 occasions within the data sets. The existing code book initially contained 6 codes within this theme, the analysis process created an additional 3 as illustrated in fig 6.

The results are structured by first discussing examples of researchers observations, followed by a narrative with example extracts from the focus groups. Finally, examples from the workshops are presented which focus on multidisciplinary collaboration and engagement.

4.1 Researchers Observations

The researchers directly observed each workshop and took notes of the site team’s interactions using the VR headsets. The researchers observed that regardless of age or prior experience using VR, the site operatives and site management very quickly engaged with using the headsets. Interestingly whilst the operatives had no prior knowledge of the site or the specific constraints, within minutes they could orientate themselves which allowed them to actively participate in the workshop. Researchers noted that the site team openly discussed their ideas and proceeded to test them within the virtual world. In further workshops, previous plans were also discussed by participants, in these instances the researchers noted an impressive retention of information. Fig. 7 shows an example of an observational note made by one of the researchers during the first workshop in relation to multidisciplinary collaboration and engagement.

4.2 Focus Group Results

During the focus group, the site team were asked their views around the use of VR and if they felt this had an impact on their collaboration and engagement within safety and plant logistics planning. From a site operative perspective, they claimed that these immersive forms of workshops assisted in their engagement into the planning process, significantly more than the traditional 2D plans they were familiar with. Operatives also explained that involving them during discussions around site planning were welcomed, as CS O1 noted "*we are used to management telling us how it is* […] *for us we are more or less told what's happening, where it's all going*". Some operatives also identified that implementing virtual reality within the workshops positively influenced their awareness of project specific hazards, and allowed them to collaborate with the project team effectively. To evidence this, one site operative commented *"using this* [VR] *and involving us* [operatives] *is helping us understand the hazards* […] *and that will have a positive impact, there is no question*" [CS O2]. For site managers they often linked multidisciplinary collaboration to the improved visuals and communication, allowing the team to share ideas more effectively. For example CS SM2 commented:

> "*well just look at this project, when we have used this* [VR] *just look at what we managed to find, how effective it was. It was so easy to discuss that amongst ourselves and to communicate with the operatives too. That's a huge benefit to us as a site team* […] *bringing everyone together to talk about safety is the point, this added to the communication and engagement*"

The site team were asked to describe what features of VR could be useful in assisting multidisciplinary collaboration during safety and logistics planning. Most of the responses to this question were provided by site management, linking to the ability to test logistical arrangements and plant positioning to see them in real scale. For them, being able to quickly move the location of a crane and see the operational radius was a particular advantage during these workshops. In many examples this allowed the team (including operatives and management) to almost immediately provide feedback on the feasibility of the location and discuss possible solutions further. This also included segregation in the form of exclusion zones and signage positions. One site manager suggested that the VR environment provided the medium to explore these options more effectively than their traditional planning processes, and stated "*for project collaboration it's definitely a positive* […] *I think for me this helped facilitate a conversation*" [CS SM1]. From a safety management perspective they focused on the importance of multidisciplinary collaboration within safety, allowing the team to explore and interact with possible solutions with clearer visual references. A typical example is presented in the statement below:

> "*it's kept everyone engaged all the time* […] *looking at how we are going to do that but virtually, it's* [VR] *a great planning tool to allow the team to work together and for a project manager and site manager to get some up front ideas* […] *For me it's my job to get these guys together logistic planning wise*" [CS SO1].

According to the senior management, the value added during the safety planning process was linked to the reduction of risk through the sharing of team knowledge. For instance CS MD1 noted:

> "*it's* [VR] *had a positive impact in a preconstruction environment. From a planning point of view, it had real potential to convey and translate the plan to the workforce who are delivering*. *Certainly from a safety planning and from a logistics side this had real value* […] *If we can access the environment in a more accurate and visual way to interpret the various pieces of information and bring it together, that can de-risk a project*"

4.3 Practical Examples using VR for Safety Planning

During the analysis process, practical examples from the workshops which captured collaboration and engagement were coded within the theme. Two examples are provided below.

Example 1: Arranging Crane Set Up Locations

In planning workshop 1, the site team discussed the potential location of cranes to install the steel frame. For the 4th crane location, it had been identified that the radius area would encroach on the site car park and pedestrian entrance, initially intended as a 'no PPE zone' area. The extract below details interdisciplinary collaboration between the site team during the workshop.

> CS O1: "*If it's going to move there I would say that the fencing needs to move towards the welfare area, we need more room to operate the crane*"

> CS SM2: "*The radius is now in our offloading area on this lift*"

CS SM1: “*We might have to use the overflow car park as there is not enough space here now, we also need to maintain segregation for the main pedestrian access*”

CS SM2: “*Those areas will need fencing off so we can back in the steel deliveries and secure them whilst they are being offloaded. That whole area to the left and from the gates will now need to be a PPE zone*”

Noticeably, this exchange highlights the sharing of knowledge amongst the site team when exploring logistics solutions, including the site operatives who were new to the project. During this discussion the model was updated within the VR environment, allowing the team to check the feasibility of the proposed arrangements. In this example, the site team discussed and agreed: pedestrian entrance segregation, vehicle locations for offloading, inclusion of PPE zones and additional banks person. Fig. 8 shows the visual display through the VR headsets and a progress photo taken during the execution on-site, showing a close match to the plan.

Example 2: Co-ordination of Traffic Arrangements - Concrete Pour & Steel Erection

During planning workshop 2, site managers and the project manager were exploring the traffic arrangements for several activities due to take place simultaneously. This included pouring of the ground floor concrete slab, the final phase steel frame erection and installing the perimeter handrail to the upper floors. The below extract is taken from the workshop.

CS PM1: “*I think the concrete pump could go in that corner of the build, we have room to set up there*”

CS SM1: “*We would come in through this entrance as the crane is still in operation using the other, then reverse up to the pump by turning there*”

CS PM1: “*Yes I think that’s best, if we minimise reversing by turning there, they can reverse up to the pump, that would be the best way. Segregation can be in place along that line and back through the midpoint of the build, gate entrance over here with PPE point*”.

As with the previous example, the model was updated within the VR environment. For this example, the team discussed and agreed: site plant / concrete vehicle movement, activity / vehicle segregation, separate offloading areas, pedestrian entrance and PPE zone. Fig. 9 illustrates the visual displays through the VR headsets and progress photos taken during the execution on-site, showing a close match to the plan.

5 Conclusions & Recommendations

This paper aimed to document practical accounts of using VR within a live UK based project, assessing the impacts on multidisciplinary collaboration and engagement during safety and plant logistics planning. This study adopted a case study strategy, using real project information and collected qualitative data through observing interactions, and conducting focus groups with active site team members. The results provided a unique insight from a site team perspective and indicate that the use of VR had a positive impact on collaboration, specifically the promotion of communication and inclusion when compared to the more traditional approaches. The researchers noted that irrespective of participants knowledge of the project, they were able to effectively contribute with minimal time to familiarise themselves with the site. Moreover, the practical examples presented in this study indicate that safety and plant logistics planning using immersive environments can actively encourage multidisciplinary collaboration and enhance team engagement, allowing more effective knowledge transfer. In this case study the on-site team welcomed the integration of VR as part of the planning process. Results shows these tools have the potential to help reduce project risk by identifying hazards, allowing for more accurate communication and testing of plant logistics. The practical examples also show that the use of VR can assist in the efficient creation of detailed plant logistics in real life scenarios. On-site progress provided confirmation that the plans created in the immersive planning workshops were accurately implemented during the physical on-site construction stage. This accuracy resulted in confidence using VR during the planning process moving forward.

This study provides an on-site perspective into the opportunities to improve project team collaboration and engagement in safety planning using VR technology. Whilst this study provides results from short term use of VR within these site processes, the researchers acknowledge the studies limitations and recommend that further longitudinal research is carried out to progress this underdeveloped field. Moreover, further investigation into the practical integration of VR for project specific safety planning that includes the wider project team is also encouraged.

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Figure Captions

Figure 1 Site Safety Planning Workshop Participant Information

Figure 2 Overview of Data Collection Process

Figure 3 Site Planning Workshop Example

Figure 4 Workshop and Focus Group Participants

Figure 5 Hybrid Coding Process

Figure 6 Collaboration and Engagement Themes and Codes

Figure 7 Example of Researchers Observational Notes

Figure 8 Crane Locations & On-site Crane Arrangements

Figure 9 Traffic Arrangements & Pedestrian Segregation