38 Challenges Around Integrating Collaborative Immersive Technologies into a Large Infrastructure Engineering Project

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Abstract

Collaborative virtual reality (VR), such as room-based or CAVE-type systems, has demonstrated benefits in engaging teams in the shared design exploration. Though much research explores how virtual reality may be affecting and contributing to the quality of the team discussion for making design decisions, evidence of how this technology becomes used and adopted in practical settings remains limited. Studies from other engineering and manufacture domains consistently report on practical, behavioral and organizational challenges and more often, resistance to introducing innovative technologies and processes. This study examines how technology adopters experience virtual reality, and explores the factors determining the extent of its implementation as an innovative practice. Drawing on the concept of technological frames, we examine how collaborative VR may introduce a non-trivial process change in an organization before it can potentially become an everyday practice. A large portable VR display system was set up in the central office of a large infrastructure project over a period of one year. During the latter half of a second study we did not observe the extensive uptake and use that we and the technology sponsors within the project anticipated. To understand the reasons, we use three technological frames that allows us to examine the technology adoption and organizational change: (i) nature of technology, to understand users' view of the technology; (ii) technology strategy, to understand users' role-based views of the motivations and incentives for technology adoption within an organization, and (iii) technology in use, to understand how intended users view the technology use on a daily basis.

Keywords

Virtual reality • Technology frames • Project-based organization

38.1 Introduction

Virtual reality (VR) has been around for several decades, but recently has gained traction as a technology for visualizing building and infrastructure design bringing the possibility of improved communication through shared visualization [1]. This renewed interest coincides with the noticeable rise in offer of low-cost consumer market virtual and augmented reality technologies. While single-user wearable technologies may easily find their use on construction sites, the use of large projection-based collaborative VR systems in practical settings still lags despite their benefits for collaborative decision-making [2–4]. The potential of such technologies to act as communication catalysts parallels a strand of research

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that points that communication methods, collaboration sessions, and contractors' involvement in design reviews, are critical for achieving high performance outcomes [5]. Gathering project stakeholders alone is insufficient, but engaged and informed collaborative decision-making will greatly depend on the stakeholders' ability to visualize and understand the project information. Virtual mock-ups using immersive projection displays have been shown to help project teams better understand the design and promote conversations that are valuable for problem solving [6–8].

In this paper, we look into the literature on organizational context of construction technology-related innovation practices and the relevance of the technological frames to study technology adoption. To examine how adopters experience virtual reality, we draw on a two-phase study in which we set up a large-screen portable VR display system in the central office of a large infrastructure company over a period of one year. The initial phase observations and participant surveys indicated the value of the technology to engage teams in the design discussion, further confirming that room-like VR acts as highly sociable environment conducive to collaborative design review tasks. This resulted in the company innovation team's commitment and interest to incorporate the technology on a project in a more structured manner in the subsequent 6-month research phase. However, in the second phase the technology was not utilized in the way we anticipated. To understand the contextual factors and possible reasons, we use the concept of technological frames to examine how collaborative VR as a novel technology may introduce a non-trivial process change on a megaproject before it can potentially become an everyday practice. The discussion and the presented findings directly contribute to the knowledge of how collaborative virtual reality as an example of innovative practice becomes adopted in practical settings through resolution of tension between stability and change in a specific context. More broadly, the goal is to expand an understanding on the changing practices and the technology adoption process in a project-based organizational setting.

38.1.1 Organizational Context for Innovation

Innovation in construction has been discussed through a broad range of sociological and economics approaches [9, 10] and also through application of diffusion of innovation perspectives [11, 12]. Rogers [11], outlines that innovations gradually become diffused by starting with initiation, which involves recognizing a need and identifying fitting innovation before proposing it for adoption. Decision to use a selected innovation typically comes from higher organizational members and is subsequently imposed onto lower level team members [13]. Implementation takes place when a decision-making unit (individual or an organization) puts an innovation to use and often involves overt behavioral change [11]. However, as Rogers also points out, problems in how to exactly use the innovation may surface at the implementation phase. When organizations, rather than individuals are adopters, these problems are likely to be more serious and diminish the benefits from innovations. Innovative aspects brought by technological changes are further reflected in procedural, managerial and business model changes that gave rise to the need for "change management" [14] that extends beyond simply installing the equipment and having trained people to use it [15].

To understand how such changes unfold, it is important to account for the recognized distinctiveness of the organizational context of the construction sector. Namely, the project-based nature of construction tends to result in instances of innovation taking place primarily within projects [16]. At the same time, the challenge to transcend the success of a project-based innovation perhaps resides in a stark contrast between the limited duration of a construction project and a continuing technology-mediated change processes [17].

38.1.2 Collaborative Virtual Reality in Construction Practice

Collaborative practices increasingly focus around 3D models at a realistic scale, though the scale at which the models are viewed resides within the size of the display media. This is particularly relevant for tasks that rely on adequate spatial understanding, where a viewing perspective (e.g. object-centered vs. viewer-centered) and the viewing scale (e.g. monitor vs. large screen), can affect the way users extrapolate information. Therefore, both the choice of a medium and a representation play an important role in how the information is perceived and evaluated [18, 19].

In addition to potentially simulating built environment in a visually more compelling manner, virtual reality often contains features that allow the user to dynamically navigate the virtual environment, switch between different viewpoints and viewing perspectives, access maps, markers or otherwise more meaningfully interact with the displayed information. Comparing how immersive VR, non-immersive VR or paper as a design medium supports various steps in the architectural process, experimental studies [20] suggest that large display immersive VR enable a more intuitive design review in terms of presentation and perception of space. Experiments and user tests have similarly confirmed the value of using large display collaborative VR systems in: design review and construction planning [21–23], on-site safety training [24], computational fluid dynamics [25], as well as overall effects of immersion on explorative analysis of 3D data [26]. The value of using large-display collaborative VR for design has been primarily associated with its ability to support the communication and understand users' reactions to design and their experience in virtual spaces [6, 27, 28]. Furthermore, the use of large display immersive VR for design review has been indicated to affect collaborative aspects through enabling distinct interactions among project stakeholders and enhancing the client engagement [29]. While collaborative VR presents opportunities to effectively engage a broad range of users in a shared conversation with the digital prototype, it is the adoption of single-user wearable VR that has had most uptake within the industry.

38.1.3 Technology Frames as a Theoretical Lens

Based on the previous studies, we can consider collaborative virtual reality to carry transformative potential for the design and construction practice, especially in instances such as interdisciplinary design reviews. Nevertheless, despite the initial enthusiasm around the perceived benefits and continually decreasing costs, there is relatively little uptake of such systems in the every-day practices of delivery in the sector. Studies on technology adoption that may prompt process change provide some clues to the potential reasons, such as organizational roles, their involvement in the decision making process, incentives and value misalignment among other [11, 30]. Other studies point to the interpretive nature of technologies where subjective goals result in different user groups using the same technology in different ways [4, 15].

Technology frames offer a helpful lens to understand how such technologies are interpreted among different users in the contexts specific to the introduction, adoption and subsequent implementation of technology [31] and is specifically useful for (change) managers and organization development specialists [14]. When developing their contribution to social-cognitive theory, Orlikowski and Gash [32] argued that the differences in social groups' knowledge, views and expectations of a technology (i.e. frames) can often hinder its effective implementation. To understand why different organizational groups (e.g. based on job roles or experience) may react differently to a technology-enabled change initiative, they defined three main domain frames that look into: (1) individual views of the nature of technology; (2) technology strategy and the reasons for its implementation; and (3) technology-in-use in terms of changes in work processes, incentives and culture [14]. Technology frames thus seem to be particularly relevant in the context of change management where knowing how people think and perform when using specific technologies can enable change managers to implement technology-based changes that also account for changes in organizational culture and employee skills. The point of departure in this study is to understand how collaborative VR becomes used and adopted in a project-based context, and what may be the contextual factors shaping actors' frames of reference for interacting with the VR system in a particular way.

38.2 Methods

Taking a qualitative approach, the study draws on the concept of technological frames to understand the contextual aspects around how project teams mobilize collaborative VR on a megaproject. In the first of a two-phase study, a large portable three-screen VR display system [33] (Fig. 38.1, left) was set up in the central office of a large infrastructure company in the UK over a period of three months starting October 2015. The initial set up and user testing resulted in an interest to incorporate the technology in a more structured manner in the subsequent research phase of six-month duration, starting August 2016. To address the participants' views on how the technology might better support their infrastructure engineering practice, in the second study, the three-screen, rear-projected VR has been replaced with the four-screen front-projected VR system (Fig. 38.1, right). The main adjustments to the VR technology included the provision of a projected ceiling; reduced footprint by changing the projection system from rear to front; streamlined workflows for converting the project teams' native files for VR simulation, and the relocation of the VR into a larger room which included a meeting table.

Data was collected through field notes and both formal and informal conversations with approximately 30 project engineers and managers who used the technology in both phases. Three formal interviews lasting between twenty and sixty minutes were conducted at the end of the second phase of research. The primary goal was to understand the context specific aspects and users groups' experience and interpretations of a collaborative VR in the infrastructure engineering firm distinctively based on a unique megaproject.

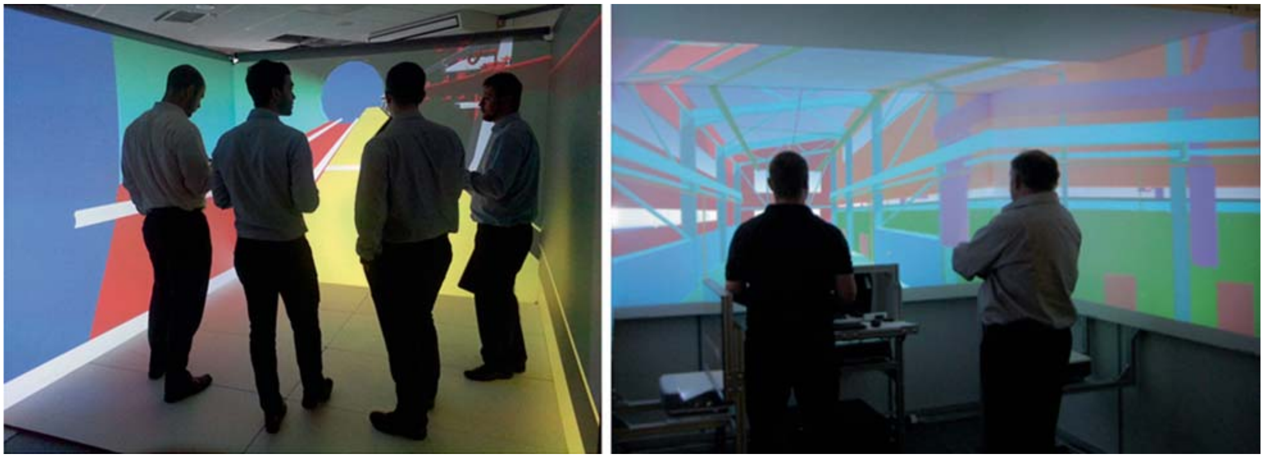

Fig. 38.1 The VR system at the company offices: phase 1 (left) and 2 (right)

38.3 Findings

The findings presented below are organized around how two dominant user groups (project team members and project managers) view the room-like VR in terms of its: (i) nature, features and capabilities; (ii) use strategy, motivations and incentives for technology adoption, and (iii) envisioned use on a daily basis.

38.3.1 Nature of Technology

Project team members and project managers shared similar views on the technology characteristics in terms of their experience with room-like VR and the potential benefits. The immersive aspect of the large screens and enhanced model experience both VR configurations offered were perceived to specifically benefit design communication and collaboration within and across project teams. At the same time, both groups of users raised specific technology-related challenges, mainly around the workflows and learning curve for preparing larger and complex models for displaying in VR (Table 38.1).

These findings point out the need for allocating appropriate resources, in the form of training, support as well as time needed for these technology-related challenges to be addressed. These challenges emphasize broader considerations that can be incorporated into an implementation strategy for novel technologies and processes.

38.3.2 Technology Strategy

Defining the value of collaborative VR resides in knowing who the target users are and what specific tasks they are envisioned to do. Room-like VR is seen as considerably-sized technology to introduce a change in daily work processes. As seen by project team members, part of the strategy is to ensure *communication* to inform, familiarize, and generate interest among potential users in a project team to gradually build knowledge around what works well for continued deployment. In

Table 38.1 Perceived benefits and challenges around the room-like VR technology

Benefits	Challenges
Projected ceiling for viewing overhead system	Handling large size models
High resolution (1080p@60 Hz)	Conversion issues—geometry and textures
Immersive experience	Revising the model on the spot, mark-up
More streamlined model development workflow	Navigation sickness
Stakeholders and client engagement	Location-access and time to travel

terms of communication, the project managers indicated that the company's process for rolling the technology out involves the Innovation team, which produces briefing notes on each innovation that are shared. As a way to increase the chances of successful deployment, additional methods for familiarizing the teams include newsletter and simple communication pieces to encourage interest. The innovation group, though acting as a driver for procuring novel technologies and practices, was however seen as insufficient to alone secure a successful diffusion and adoption of the procured technology. In practice, knowledge around how these technologies work and can be used is built within smaller teams of self-motivated individuals who end up appropriating and championing the use of this technology. The tension between what is seen as the predominantly top-down approach to implementing VR technology and the lack of bottom-up authority for its adoption is reflected in differing motivations for its use: "*[The company] wants to be seen as innovative, that's why we have the equipment here [VR], […], but they only came along from a directive, from the board, not because we needed it, not because management said we need it*."

Overall, both user groups emphasized their positive attitude towards collaborative VR as innovative technology, but framed their views around their distinct role expectations. While for some of the members "*Technology is what I have to keep up with, cause if I don't, I get fired*"; and "*I embrace technology in a way I have to do what I'm supposed to be doing. I don't like technology for technology's sake*"; the project managers' framing of the value of room-like VR highlighted a stronger emphasis on the potential benefit of the technology for the entire project: "*Why use VR? I am accountable to the project stakeholders- as PM my goal is that we don't have problems in the future. […] Design review we do anyways and look at a 3D model—only the way the model is presented [in VR] is different*."

As both user groups pointed out, the difficulty in using collaborative VR appears at the team-level due to individuals' perceived priorities of other daily tasks and hence, insufficient time or guidance on integrating the technology without much disruption: "*Ultimately, if the person on the ground just did not have time and there are no additional resources to implement, it is a struggle*". For project members and engineers, beyond those who are personally motivated, the question "*What's in it for me*?" reflects a broader attitude that the time and effort required to use VR still outweigh the positive views and appreciation of the immersive experience it offers, claiming that: "*We are here to build a railway, not to test technology*." This view appears to be grounded in the assumption that the use of (novel) technology is an appendage to the daily responsibilities for which there is no allocated time. Even when the individual members assume the role of a technology-champion on a project, once the project teams disband and the team members relocate to different projects or roles, the experience and knowledge built during the project is lost.

38.3.3 Technology in Use

For collaborative VR to become more used in interdisciplinary design reviews on a megaproject, both the project team members and managers indicated an array of logistical, resource and strategy considerations including access and location of the technology, timeframe for its implementation that would allow for necessary training, and raising awareness of the value and goals of the technology more systematically.

Both groups pointed that the location tends to be an issue for geographically dispersed teams which is typical in this case. Project managers further explained that the central offices where the collaborative VR was located are mainly populated by chief personnel and mostly used for final stage design reviews when no further iterations are expected. Subcontracted design offices also tend to hold design reviews at their locations: "*Getting all the sites that were not centrally based to come and have design reviews, getting CEG's buy-in was a struggle*."

Access to the room revealed the need to specifically address the protocols around using the space. While the room that housed VR was publicly available, access to the technology still required signing-in day ahead of the intended use and passing through security in addition to common and non-trivial time-consuming travelling logistics. Hence, finding the most appropriate location for engaging other site teams should balance the requirements and availability of such spaces with a fairly open, but monitored access, and with an adequate and dedicated technical support.

Framing of the VR use as part of daily practices highlighted the need for consistency in information requirements for conducting design reviews, as project managers noted that currently 3D models may not always be required: "*This mostly depends on the type of design reviews—single discipline design reviews are done probably with 2D drawings only, but interdisciplinary design reviews require a 3D model*." Furthermore, reviewing the model on the screen follows a different narrative from that viewed in the large scale VR, where the former tends to be more structured to look for specific problems in the model, whereas the latter allows less constrained exploration of the model and potential discovery of unanticipated issues. This revealed a seemingly persistent challenge of the reluctance around using large scale VR resulting from concerns of incomplete, inaccurate or not up to date 3D models that in turn would be perceived as increased scope or liability. However, this infers coordination challenges for maintaining an up to date and accurate model that has been checked ahead of the design review.

38.4 Discussion and Conclusions

This work contributes to research on the uptake of VR technology in practical settings using a megaproject case study context. Despite the interest and positive experience using the technology, we did not observe the extensive uptake for interdisciplinary design reviews that we and the technology sponsors within the megaproject anticipated. The three technological frames [14, 32] used to examine the technology adoption revealed a number of strategic, logistical and organizational considerations to ensure successful implementation of technologies such as collaborative VR.

The project team members' and project managers' framing of the *nature of technology* indicated shared enjoyment of the immersiveness and enhanced model experience, seen to benefit design collaboration within and across project teams. Addition of the projected ceiling in the second VR configuration was specifically perceived as useful for the ability to review overhead engineering systems. At the same time, the perceptions of added scope of work in terms of using, or learning how to use the technology need to be addressed through a conversation with the target users in defining values for introducing process-changing technologies, such as collaborative VR and adequate resources to support their deployment.

Considering the *technology strategy*, the value and motivations for using collaborative VR are framed around particular roles expectations where project managers consider the value for the project performance, while members may view it as part of their individual performance. This brings about the importance of carefully considering communication about the technology and its potential, whilst also ensuring time and training needed to use it at team levels.

The user groups' framing of the *use of technology* highlighted practicalities of accessing the facility and the incentives for finding time to use novel visualization technology. Specific concerns were raised by users around the need for sufficient contact time with the technology to enable team members to learn how to use, test and adapt the technology over time to enable combining the use of collaborative VR alongside their current practices.

This study extends current understanding on the changing practices and the collaborative VR technology adoption project-based organizational settings. The study has broader implications and recommendations for practice by revealing context specific organizational challenges in technology adoption. Despite the excitement about the collaborative VR, the contextual complexity of a megaproject, role distribution and the logistics brought about notable managerial challenges for its adoption in everyday practice. The study also suggests the potential of mobilizing the concept of technological frames through action research for revealing and monitoring change in technological frames within organizational adoption of technology innovation.

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