Technology-enabled collaborative spaces for design and construction reviews

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Abstract

Design is an important phase of the facility life cycle as it has a direct impact on overall performance, cost and success. Collaboration in design increasingly involves the use of digital technologies to help geographically dispersed team members and stakeholders to visualise and interact with project information to make decisions. Collaboration can be either co-located or remote, and in both instances benefit from digital technologies ranging from audio, video, or web conferencing to more advanced immersive room-based systems, designed to deliver different types of user experiences. This paper discusses the use of digital technologies for collaborative working on project tasks in synchronous remote and co-located settings, and rehearses the considerations required when designing and delivering technology-enabled collaborative spaces (TeCS). Following an initial review of the related research work in these areas, an integrated approach to the design of TeCS is proposed together with a framework to support the capture of user requirements, deployment and use of TeCS. The end users' appropriation of such spaces in shaping team collaboration beyond the initial technology assumptions is also explored. It is expected that this will help inform the design and evolution of future TeCS for co-located and remote work settings, as well as guide in developing a framework for evaluating successful deployment and use of TeCS in design and construction projects.

Keywords: Design, collaboration, virtual, collaborative spaces, digital technology

1 Introduction

In an increasingly competitive marketplace, project teams across industry sectors are tasked to run and deliver projects successfully through optimum use of talent, knowledge and resources. Such projects are often of high value, time-critical, complex and require key stakeholders to work together effectively to meet users' requirements. Digital technologies have become integral in architecture, engineering and construction (AEC), as well as oil and gas industries to increase the project efficiency and safety through, for example, enhanced real-time monitoring, early detection and diagnosis of issues, and generally advanced communication and collaboration between the stakeholders (Rindahl et al 2014). Given that projects are increasingly coordinated globally, project teams rely on a range of digital technologies to remotely collaborate (Fruchter 2006) from early project planning and design reviews, to operations and maintenance. Digital technologies for remote collaboration range from traditional audio-video desktop videoconferencing to fully immersive and interactive technologies (Oblong Industries 2013) and their market share is expected to grow significantly by 2018 (Forrester Consulting 2012). Table 1 summarizes main types of collaborative technologies used for various project tasks in the AEC, oil and gas, manufacturing, nuclear, and transportation industries. Although the adoption of advanced virtual collaboration technologies in some industry sectors is still in early stages, oil and gas and the nuclear industry for example, frequently rely on advanced collaboration environments for daily operations, such as real-time operations control and crisis management centres, often coordinated globally (Van den Berg et al 2013). Thus, both globalization and project delivery requirements have given rise to a growing virtual space and innovative digital technologies to support virtual work settings and collaboration.

Table 1 Overview of collaboration technology use in different industry sectors

Industry sector	Virtual collaboration technologies used	Typical tasks and activities used for
Oil and Gas, AEC, Manufacturing, Nuclear, Transport	Audio, Video Desktop/screen sharing	Project communication, planning, design data sharing, design reviews, review meetings, training, support, regular meetings
Oil and Gas, AEC, Manufacturing, Nuclear, Transport	Room-based High Definition video Telepresence	Senior employee meetings, C-level strategy meeting, training, customer meetings, product launches and presentations
Oil and Gas, AEC, Manufacturing, Nuclear, Transport	Interactive technologies (whiteboard, touchscreen)	Idea brainstorming, idea development and innovation, problem review and resolution, training
Oil and Gas, AEC, Nuclear, Transport	Virtual collaboration rooms and immersive environments	Data and information sharing, Data visualisation and analysis, reviews, problem resolution, training, product demonstrations
Oil and Gas, Nuclear, Transport	Real-time control and crisis management centres	Real time monitoring of operations (e.g. drilling in oil and gas) and management of assets, crisis management and resolution, emergencies

In the context of this paper, collaboration is defined as a process where a team of two or more people work together on a common task to achieve a shared goal, while collaboration technology refers to one or more computer-based tools that supports the team in communicating and coordinating relevant information (Zigurs et al 2006). Similarly, geographically dispersed teams use virtual collaboration technology to communicate and coordinate project tasks. Collaboration technologies are typically deployed in dedicated room-based environments, open space office environments or at the office desk thus becoming part of the physical office space in which they are deployed and used. An understanding of this physical space and the surrounding physical office environment is likely to impact on the design, success of the deployment and use of such technologies for collaboration (Mittleman 2009). While the types of digital technologies for collaboration are generally well known and explored (Frost and Sullivan 2012), the way physical aspects shape the deployment of collaborative technologies and respective collaborative practices is still little studied. (Brager et al 2000) note that while organisations are adopting new work models impacting the group and individual spaces used for collaborative working, the space design typically does not adequately support the desired level of collaboration that is most likely to yield high value outcomes to organisations. Specifically, spatial attributes and technical features of the environment that support impromptu interactions, casual meetings, and collaboration need to be identified and better understood. To explore this physical aspect and spatial characteristics of both virtual and co-located collaboration we will use the term **technology-enabled collaborative space** (TeCS).

This paper first identifies the types of tasks supported by virtual collaboration technologies in the AEC and oil and gas industry; then, it reviews the process of how such technologies are designed to support specific tasks, and how they meet the users' requirements once deployed. Informed by the existing knowledge and the lead author's extensive industry experience of designing, implementing and deploying collaboration technologies for various industry customers, an integrated approach for the design and evaluation of TeCS is proposed. Initial observations of the use of TeCS and virtual collaboration technologies in the context of construction design projects and other industry sectors such as oil and gas are considered along with the lessons learned from participating in the design and deployment, as well as training and supporting the users of collaborative technologies.

2 Background

2.1 The technologies, systems and spaces supporting collaboration

Research initiatives such as Groupware, Computer Supported Cooperative Working (CSCW), Roomware (Streitz et al 2001) and more recent Blended Spaces (Benyon et al 2012) explore how people work together, either as individuals or in teams, and what digital technologies they use to collaborate. For example, in (Ellis 1999) Groupware is defined as hardware and software technology to assist interacting groups and CSCW is defined as the study of how groups work, and how we can implement technology to enhance group interaction and collaboration. (Benyon 2014) notes that Groupware is rooted in an understanding of the social features of computing; general and personal use of computing rather than work settings. CSCW on the other hand, explores the use of digital technologies in work settings and how they support team collaboration in the context of both time (i.e. synchronous and asynchronous) and space (i.e. co-located and remote), and thus helps to categorise digital technologies used to support collaboration in these specific instances (Johansen 1988).

The term Roomware was first coined by (Streitz et al 2001) to introduce the concept of physical space in addition to the technology as parts of collaborative environments. Similarly, (Jetter et al 2012) propose the idea of blended interaction – a conceptual framework which examines the extent to which the users perceive a digital interface as "natural". (Benyon et al 2012) applied this idea to the design of Blended Spaces to create a more harmonized and unified user experience. Blended spaces combine both physical and digital to arrive at a design which maximizes the relationships between the spaces and also helps to develop the touch points between them. Furthermore, (Bardram et al 2012) introduced the concept of ReticularSpaces as the concept for a smart space system built on the principles of activity-based computing support in physically distributed and collaborative smart spaces. The use of digital technologies for facilitating both co-located and remote synchronous collaboration is key to design and construction projects due to a need to involve different project stakeholders during tasks such as design reviews or coordination meetings where shared understanding for informed decision making is critical.

2.2 The relationship between the task, technology and context

Digital technologies supporting synchronous collaboration in design and construction range from standard audio-video conferencing and interactive whiteboard technologies to advanced virtual collaboration rooms and immersive environments (Frost and Sullivan 2012). Although the time-space groupware matrix (Johansen 1988) helps classify the technology to be used in different time and space scenarios, it does not however provide an understanding of the specific tasks and user requirements that would guide the deployment of relevant collaborative technologies.

(Zigurs et al 2006) argue that, rather than defining new typologies of technology and tasks, a greater complexity and need is in integrating these to evaluate the technology fit to the tasks. To address this complexity, a clear understanding of the contexts in which collaboration unfolds is critical. As virtual teams and organization become more dispersed, their reliance on collaboration technology for supporting a variety of functions becomes greater, highlighting the need for the technology to create a shared space (Zigurs et al 2006). The classification of collaborative tools is applied to a software development project context with distributed teams involved in tasks such as conceptualizing, designing, building, debugging and testing in (Soriano et al 2010). The collaborative need of the team depends on the factors such as team structure, or the location of the team members, so that collaborative tools are designed to meet specific requirements, including the physical space. However, (Soriano et al 2010) further assert the unlikelihood of designing a collaborative space that would meet every possible collaboration need, and suggest instead that the teams should use a classification framework to select the appropriate collaboration tools that would meet their specific activity needs. For example, comparing the collaboration technologies and systems features, (Bafoutsou et al 2002) observed that file and document sharing is the most required collaborative function, while the need for electronic meetings is in the case of remote participants making important decisions for the work in progress. Dominating the design and construction practice, Building Information Modelling (BIM) and Computer Aided Design (CAD) technology solutions, while promoted as collaborative, are often information-centric and do not effectively support collective discussion of ideas and problem solving (Bassanino et al 2013). A framework, based on views of the Meeting Process, Team Member, Information, User Interface, Workspace and Application is proposed instead, as a way to emphasize the human, or a team-centric perspective of collaborative technologies to enhance team communication and problem solving tasks (Bassanino et al 2013). Yet, this approach focuses on co-located design reviews and the conclusions suggest the opportunity to further explore the use of technology for collaborative design tasks in virtual work settings.

2.3 Design and implementation of virtual collaboration technologies and spaces

Other current approaches to designing technology-enabled collaborative spaces examine how user requirements are considered in the design process. Of particular interest are collaborative project design tasks that require stakeholders to visualise complex data, collaborate on multiple documents simultaneously, review and annotate documents, share applications and facility information models and modify information in real time.

(Mival & Benyon 2013) designed an interactive collaborative environment (ICE) as a flexible space to support both co-located and virtual collaborative meetings enabling users to bring their own devices and content into the environment. It is designed as a multi-user, multi-orientation, multi-screen and multi-touch environment for both local and remote collaboration activities. The design approach is not to enable technology to drive application and use of space but to incorporate the needs, wants and activities of the people using the space. (Mival & Benyon 2013) illustrate this approach through what they describe as robust, easy to use and fun design of the ICE physical space, in which, similar to Blended Spaces (Benyon et al 2012) they combine the analogue and digital aspect in a "blended" way by relying on the users' familiarity with tables for interaction and interactive whiteboards using pens to easily access and interact with the content (e.g. document and applications). The study also reports benefits of such blended spaces and experiences in supporting creativity during collaborative meetings. When introducing the idea of blended interaction, (Jetter et al 2012) identify four things for designers of collaborative spaces to focus on: 1) the individual interaction, 2) the social interaction, 3) workflow, and 4) the physical environment. Other, more intensive real-time collaboration scenarios include real-time monitoring centres in the power industry (Wigdor et al 2006), common information spaces to support knowledge-intensive work in the oil and gas industry (Hepso 2009) or advanced control room environments (Hurlen et al 2012; Koskinen et al 2011). Furthermore, (Rindahl et al 2014) identify the challenges in designing collaborative work environments in what tends to be the focus on technology and the vendors' failure to fully understand user needs and their changing work practices (e.g. a change in how virtual meetings take place, information shared during collaboration, or visualization and interaction requirements).

Although different design approaches have been taken in designing the collaborative environments discussed above, they reveal that the physical environment and space is a key part of the design of collaboration technologies and spaces. This is further demonstrated in (Haworth 2011) where the reasons for team members to meet are linked to their collaboration needs and collaboration culture required for their meeting. This guides with the design and implementation of appropriate types of collaboration spaces within the workplace such as presentation spaces, tactical execution spaces, strategic thinking spaces and social spaces.

2.4 Types of virtual collaboration technologies used for construction design tasks

Early digital technologies for collaboration were mostly based on audio conferencing with limited abilities for participants to review or modify documents. While audio conferencing remains widely used, recent advances in technology offer integration of shared video, desktop or a screen, with an ability to interact with digitally displayed information through novel collaboration experiences delivered within dedicated in-room or open spaces (Benyon et al 2012). In (Knoll 2013), a performance-based approach is taken to design collaborative spaces where the most rapidly growing types of collaborative spaces are highlighted as the ones which support brainstorming, small unplanned meetings, video conferencing and project team work. Table 2 lists collaborative technologies commonly used for synchronous remote collaboration and compares them by their spatial requirements for typical tasks involved in design review meetings. These technologies can also facilitate both co-located and virtual collaboration.

Table 2 Overview of virtual collaboration technologies for synchronous collaboration on construction design review tasks

Virtual collaboration technology	Typical spaces used in	Typical tasks in design and construction	Approach for design of the technology or space	Level of interaction and collaboration (Low-Medium-High)
Audio conferencing	Room-based Desktop Mobile	Small group meetings, problem resolution	**User group:** two or more people **Use:** easy, versatile, mobile Information access: separate.	Low interaction and collaboration.
Video and web conferencing	Room-based Desktop Mobile	Project meetings, design reviews training, problem resolution, data sharing, support	**User group:** two or more people. **Use:** easy, versatile, mobile Information access: viewing enabled through desktop/ screen sharing.	Medium interaction and collaboration.
Open space video conferencing kiosks	Open space in office	Project meetings, training, problem resolution	**User group:** two or more people **Use:** ad-hoc, quick meetings. Information access: viewing enabled through desktop/ screen sharing.	Medium interaction and low collaboration.
High definition video conferencing suites and Telepresence units	Room-based	Regular project meetings, design reviews, training, customer meetings	**User group:** 5-10 people **Use:** intermediate/assisted; dedicated hardware, software and infrastructure Information access: limited viewing through desktop/ screen sharing.	High social interaction and medium collaboration.
Interactive whiteboard technologies	Room-based Mobile	Brainstorming, document review and markup, training, innovation meetings	**User group:**1-5 people **Use:** easy to medium, small to large groups. Information access: visual display of information, real-time annotations.	Medium interaction and medium collaboration.
Advanced virtual collaboration rooms and immersive environments	Room-based	Data visualisation, analysis, reviews, problem resolution, training	**User group:** small/large teams **Use:** advanced/assisted Information access: visual or simulated data, multimodal display of information, navigation and interaction.	High interaction and high collaboration.

2.5 Deployment of collaboration technologies

Along with the "people-led" design approach used to design the interactive collaboration environment, (Mival & Benyon 2013) propose a six-stage protocol for clients who seek to develop collaborative systems. This approach in the form of an ethnographic study would involve attending and observing daily briefings and internal client meetings, documenting the communication and information workflow between participants, recording the users' needs and concerns to capture the users' requirements, and lastly obtain the buy-in of the actual users of the space. Furthermore, the importance of integrating people, processes, facility and technology are highlighted in establishing a Collaborative Work Environment (CWE) framework for large-scale implementation (Rindahl et al 2014; Van den Berg et al 2013). Better understanding of the users' needs and collaborative work practices remains a challenge and is critical for the technology design and deployment process (Rindahl et al 2014).

The adoption and deployment of virtual collaboration technologies has typically been the responsibility of the IT department within organizations, but the process is changing due to a growing number of different stakeholders involved in the decision making process. For example, a typical construction project involves a project manager/team leader, multi-disciplinary engineers, CAD specialist, architects, site engineers and the client, among others. To design and deliver specific collaboration technology solutions, vendors typically capture user requirements in a very traditional, technology-focused process as shown in Figure 1. This example process is based on the practical experience as a designer and developer of the technologies for supporting virtual collaborative working and the spaces they form part of.

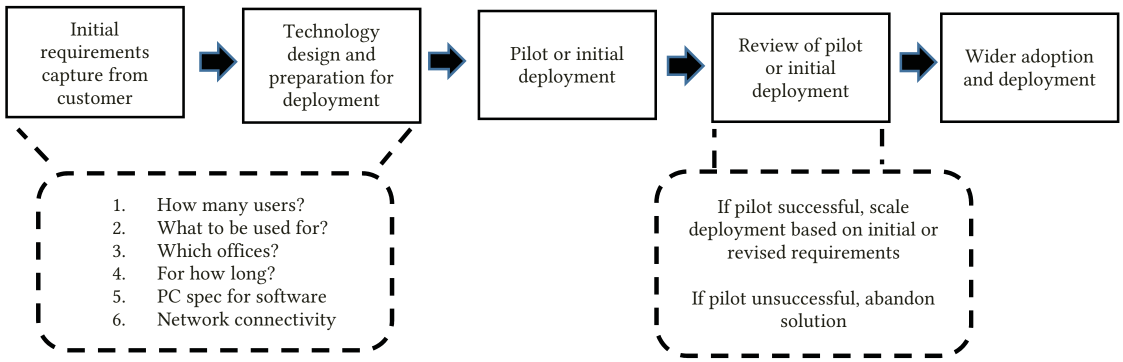

Figure 1 Example process for requirements capture for design of virtual collaboration technologies

Little emphasis however, is placed on understanding the actual space in which the technology is to be deployed and used. The process also provides limited understanding of the types of collaborative activities and tasks as the use of the technology matures and the adoption is scaled up beyond initial deployment. After the digital technologies and collaborative environments are deployed, there is a two-way effect in terms of how well these technologies meet the users' requirements and also how they may extend and shape existing collaborative practices. Studies demonstrate several different approaches to evaluating collaborative technology adoption and how their use changes over time. (Vaidya et al 2005) developed a framework, which uses the scope and sophistication of collaboration technology use as parameters to measure their adoption and help adopt suitable mechanisms to shift to an appropriate level. The scope is defined through both the frequency of use of a chosen technology to perform a task, and the proportion of a completed task as a result of using the technology. Sophistication of use on the other hand, is based on the four classes of task complexity including 1) information sharing, 2) information management, 3) group information management and 4) group synchronous decision making (Vaidya et al 2005). (Ellis 2000) proposes a different evaluation framework for collaborative systems, which distinguishes the technology space (T-space) and interaction space (I-space), and applies this logic to both evaluate the use and appropriation of the system for the relevant tasks and to compare different collaborative systems. Another study sought to develop and validate an instrument for measuring the use of collaboration technologies for both synchronous and asynchronous work, as well as for remote and co-located collaborative work (Lee 2007). The study indicated that higher task and technology scoring on a collaboration index is associated with greater usability, for example resulting in faster task completion, fewer errors, more generated ideas and greater user satisfaction. In the context of remote teams collaborating on design-related tasks, the Technology Acceptance Model (Dasgupta et al 2002) seems particularly relevant because it not only measures the users' acceptance of digital collaboration technology, but can also provide insight into how the system use influences participants' performance. These studies indicate the need for a holistic framework and standards for global, large-scale deployment and implementation of collaborative work environments (Van den Berg et al 2013).

Once the collaboration technologies have been adopted, it is equally important to understand how their use changes and is appropriated over time. In this aspect, (Goldarcena et al 2013) report on the increasing maturity of the users' understanding of the use of technology and benefits of using interactive technologies for group design and planning collaboration sessions for construction industry and academic purposes. The results of their survey of users also show broad and consistently high levels of perceived benefit of technology to support interactive group collaboration for facility design and construction. Such progression of the technology use over time is often not considered during the initial capture of the requirements, and arguably such environments need to be flexible to accommodate changes beyond the initial deployment and use. Thus, to evaluate how the system is appropriated beyond the initial requirement it is necessary to evaluate initial user requirements for designing TeCS and document changes to the original design intent.

Existing research reveals a fragmented understanding of collaborative practices shaped by the technology-enabled collaborative spaces. This is mostly evident in the significant lack of systematic research and data on team spaces that goes beyond anecdotal information (Brager et al 2000). To understand the lifecycle of the technology-enabled collaborative spaces and how they may shape collaboration beyond users' requirements, this study proposes the following approach to explore:

1. The relationship between the user tasks and technology-enabled collaborative spaces in the context of design and construction projects;
2. How user requirements are captured to formulate a design brief and used to inform the current approaches for designing collaborative spaces e.g. based on an ethnographic approach;
3. How does positioning of collaboration spaces, layout within the office and user movement affect the TeCS design; and
4. Documenting the frequency and types of uses, success level, and maturity of TeCS once they are deployed, adopted and implemented into organisations.

3 An integrated approach for technology-enabled collaborative spaces (TeCS)

Previous studies reveal that often factors such as the users, tasks and the space housing the collaborative technology are not sufficiently considered to understand their interrelated effects on effective users' interactions. The design approaches investigated reveal some importance of the physical space in the design of collaborative working environments and argue for an integrated approach in considering the space, technology and users to enhance the collaborative experience. For example, in more collaboration-intensive tasks, such as those found in advanced control rooms or war room collaboration environments (Hurlen et al 2012; Koskinen et al 2011), the design of the physical environment is key to the user interactions it facilitates. This is due to the immediacy of the collaborative activities and tasks in these environment to support real-time decision making, compared to lower-end virtual collaboration using standard audio and video communication. In the generic approach taken by most collaboration technology vendors and service providers to capture organizational needs and user requirements for such technologies, more focus is placed on the hardware, software and network infrastructure required than on the users and the space in which they will be deployed and used.

An approach that holistically considers people, technology and space in the design process and after the deployment can further inform future design and enrich user interactions within the space to support changing needs of users and changing tasks. This leads to the shift in focus from collaboration technologies alone to technology-enabled collaborative spaces (TeCS) where the technology is a part of a broader infrastructure that can be applied to both co-located and virtual collaborative working contexts (Figure 2).

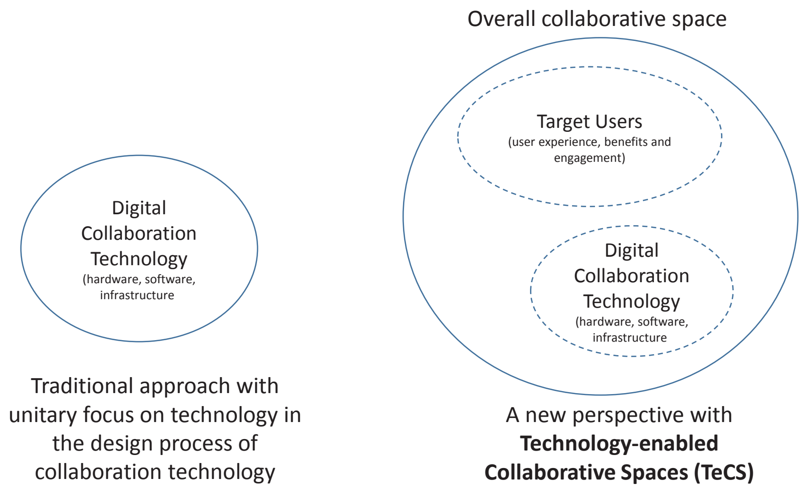

Figure 2 A high level description of the new perspective for designing TeCS

It is expected that this approach will also inform the way user and organizational requirements are captured and applied in the design process for TeCS. This would facilitate the involvement of multiple stakeholders from different parts of the organization in design and deployment stages. The holistic approach accommodates changes in user or organizational requirements over time, facilitating wider adoption and deployment. Figure 3 illustrates at a high level how the traditional process for design and deployment of collaboration technologies can be evolved to better support requirements in the context of construction design tasks in virtual work settings.

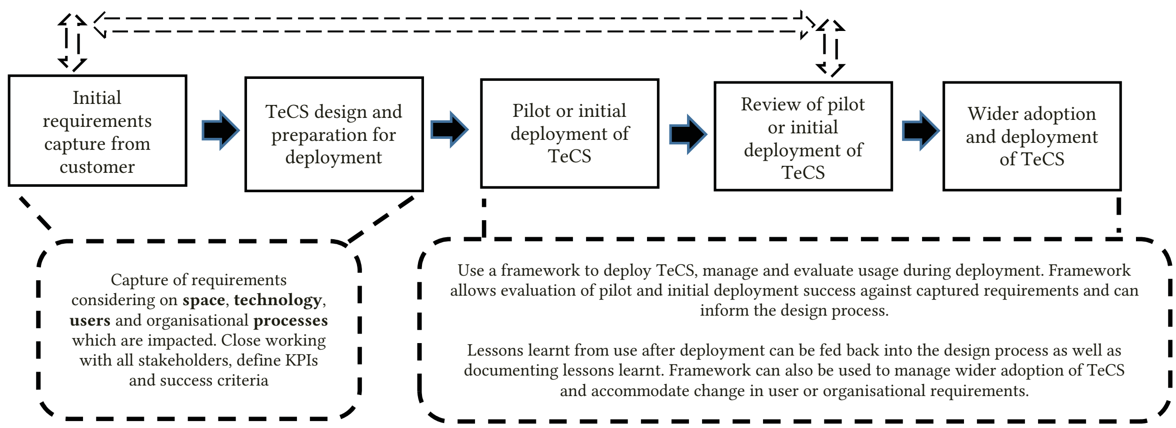

Figure 3 Proposed high level process for requirements capture with TeCS holistic approach

Building further from the presented concept for designing and deploying TeCS, the next research steps will involve ethnographic observations of currently deployed TeCS use and interviews in order to define the framework using data such as location of the deployment, layout of the office and physical space and size of the space, number of users, times of day for use, frequency of use. Further research will focus on clearly defining the synchronous collaborative activities and tasks which would take place during the design lifecycle of a construction project (e.g. design specification, document writing, data sharing, visualization and reviews, design approval, implementation, testing and evaluation) which TeCS might facilitate for individuals and teams working such projects. The use of TeCS beyond the original requirements and assumptions will also be monitored and captured as part of the framework.

4 Conclusions and future research

The collaboration landscape is changing, especially in industry sectors delivering and operating high-value complex infrastructure using geographically dispersed teams. Existing literature is primarily focused on the capabilities of the technology used with little emphasis on how people, the spatial environment and user interactions are considered in designing and deploying TeCS, as well as the flexibility of the space to adapt to changes in user requirements. There is also a recognized need to explore the use and impact of collaboration technologies and spaces on virtual collaboration in project design-related tasks. With the proposed framework for the design and evaluation of the technology-enabled collaborative spaces to support effective capture of user requirements, it is expected these will also help understand how the technology is actually used when deployed and how it may change or shape the collaboration over time (e.g. for users involved during the design lifecycle of a construction project). We seek to build on the research carried out by (Jetter et al 2012) and (Benyon et al 2012) on blended spaces and Brager et al. (2000) on the link between team spaces and the physical environment. Exploring the physical aspects of virtual collaboration will help further understand the link between the physical and digital space, participants and the collaborative tasks, especially those involving real-time decision making in project design and delivery. This framework will provide the foundation for the next stages of the research including pilot studies, active participation, and observations of the daily use of TeCS through an action research-type approach. It is expected that the work presented in this paper will guide the future research about the TeCS users and the stakeholders championing their adoption in organisations.

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