Immersive Cooperative Work Environments (CWE): Designing Human-Building Interaction in Virtual Reality

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Abstract. We propose to extend CSCW research to include the *design of buildings* for cooperative work and to engage in designing Human-Building Interaction supporting cooperative practices. Concretely, we design and implement an immersive Cooperative Work Environment in Virtual Reality using real-life 3D architectural models of a hospital. We then invite healthcare practitioners to cooperatively resuscitate patients experiencing cardiac arrest in an immersive Cooperative Work Environment. This enabled the healthcare practitioners to identify critical functional errors (e.g. how asymmetric door design compromised resurrection practices in certain situations) that were not detected through other available architectural representations. Based upon our research, we identify three design dimensions essential to creating immersive Cooperative Work Environments: 1) the *cooperative dimension,* structured as the design of interdependence, articulation work, awareness, and grounding; 2) the *professional work dimension,* structured as the design of work practices, policies, artefacts, and professional language; and 3) the *spatiotemporal dimension,* structured as the design of loci and mobility. We also identified *temporal orientation* as a cross-spanning category relevant for all three design dimensions essential to participants' navigating of the building. Temporal orientation in an immersive Cooperative Work Environment must accommodate the experience of sequential time, clock time, and action time.

Keywords: Domain-specific buildings, architecture, hospital, healthcare, building information models, BIM, Advanced Life Support, ALS, cardiac arrest, temporal orientation, collaborative virtual reality, VR, cooperative virtual environments, CVE, immersive Cooperative Work Environment

1 Introduction

Unfortunately, there are cases where hospitals are fully erected before critical architectural problems constraining healthcare practices are detected (Brook, 2018). CSCW research has shown that the architecture and physical layout of hospitals matters for how the work gets accomplished (Balka et al., 2008; Bansler et al., 2016; Bardram et al., 2006; Bénard et al., 2006; Bossen, 2002; Mentis et al., 2013; Møller, 2013). Thus, the physical layout for work must be taken into account when we design cooperative technologies (Bjørn et al., 2009; Rodon et al., 2014; Tellioglu et al., 2001). Architecture not only shapes the work; it concretely structures which temporal and coordinative activities can be accomplished. In a healthcare setting, hospital architecture determines how healthcare professionals collaborate and handle patient trajectories (Bardram, 2000; Egger et al., 1992; Reddy et al., 2002). Acknowledging the connection between technology design and architectural design, new research on Human–Building Interaction seeks to understand technology as immediately spatiotemporally immersive, thus extending the focus from the design of artefacts to the design of buildings (Alavi et al., 2016; Alavi et al., 2019).

Introducing this stream of research into the CSCW domain, we propose that CSCW research should pay attention to the spatiotemporally immersive characteristics of buildings for work and find new ways to study and design cooperative practices, technologies, *and* buildings. Architectural practices have been empirically scrutinized within CSCW research (Bratteteig et al., 2016; Møller et al., 2016). These studies demonstrate the important use of coordinative artefacts when architectural teams balance demands and needs considering materials, technology, and future use (Schmidt et al., 2002; Schmidt et al., 2004). Indeed, architectural practices involve design activities by which potential end-users "test" the functionality of architectural design. Such "tests" are often structured using physical mockups of small parts of the building or design workshops where representatives from future user-groups are shown architectural drawings depicting the future building as a prompt for discussion.

New technologies have entered the architectural practices in recent decades, transforming architectural practice in important ways, e.g., Building Information Modelling (BIM) technology, which produces 3D digital representations of architectural design (Sampaio, 2017). With the introduction of BIM technology into architectural practices, architectural teams have access to detailed 3D digital representations of a complete architectural model and continuously changing architectural plans. BIM technology has been mandatory for all architectural projects costing more than 2.7 million EURO in Denmark since 2011 (Lidegaard, 2011). Recently, architectural teams are beginning to use the available 3D models created by BIM to create immersive experiences to obtain feedback from users. However, current setups lack a cooperative component, making it difficult to examine how an architectural design either enables or constraints the cooperative work.

We propose the immersive Cooperative Work Environment approach. Scaling CSCW research *from* focusing on the design of cooperative technologies *to include* the design of buildings, we complement existing ethnographic CSCW research approaches (Bjørn et al., 2014; Crabtree et al., 2012; Randall et al., 2007) while extending and updating former research on Collaborative Virtual Environments (Benford et al., 2001) and Common Information Spaces (Bannon et al., 1997). An immersive Cooperative Work Environment is a Virtual Reality (VR) immersive spatiotemporal environment where professional cooperative work can take place in a 3D representation of a domain-specific building. The immersive Cooperative Work Environment approach allows CSCW designers to move from empirically investigating existing work practices in existing buildings to empirically examining future work practices in non-existing buildings. The research question investigated in this paper is *What design dimensions are important when creating immersive Cooperative Work Environments simulating professional cooperative work?* By investigating this research question, we introduce Human–Building Interaction into CSCW research, initiating a research stream where CSCW researchers ultimately seek to impact the design of domain-specific buildings, enabling cooperative work arrangements positively.

Note that we consider two sets of cooperative arrangements in this paper. The first is the *cooperative architectural design work arrangement*, the work of the architectural teams involved in building a hospital. The second is the *cooperative healthcare work arrangement,* the work which is to take place in the future hospital. The work practices designed into the immersive Cooperative Work Environment are the healthcare practices; however, the use of the immersive Cooperative Work Environment is to support the architectural practices. Our purpose is to create and implement an immersive Cooperative Work Environment allowing the *cooperative healthcare work arrangement* to unfold and thus support the *cooperative architectural design arrangement* in shaping architectural practices of hospitals.

We identify three design dimensions essential to creating immersive Cooperative Work Environments: 1) the *cooperative dimension,* allowing participants to experience interdependence, articulation work, awareness, and grounding in the virtual building; 2) the *professional work dimension,* allowing participants to experience work practices, policies, artefacts, and professional language in the virtual building; and 3) the *spatiotemporal dimension,* allowing participants to experience loci and mobility in the virtual building. Further, *temporal orientation* emerged as a cross-spanning category relevant for all three sets of design dimensions. Temporal orientation must be conceptually understood and implemented in different ways supporting the cooperative, professional, or spatiotemporal dimensions of the immersive Cooperative Work Environment, e.g., as sequential time, clock time, and action time.

This paper is structured as follows. First, we situate our work in the theoretical landscape of prior CSCW discussions on Collaborative Virtual Environments and Common Information Spaces. On this basis, we introduce the immersive Cooperative Work Environment as a CSCW approach to Human–Building Interaction. Next, we present our research method and detailed information about how we designed and implemented an immersive Cooperative Work Environment supporting healthcare practitioners in resurrecting patients experiencing heart failure in the real-life architectural design of a future hospital. This is followed by the results of our analysis, where we present the details of our findings, focusing on the cross-spanning design concerns for temporal orientation. Finally, we discuss our results and propose the three design dimensions essential to designing and implementing immersive Cooperative Work Environments.

2 Related Work

Prior CSCW research that inspired the conceptual understanding behind the immersive Cooperative Work Environment approach comes from three different sub-streams of former CSCW research. These are the cooperative characteristics of work, the professional characteristics of work, and the spatiotemporal characteristics of work. Below we visit each in turn; but before we dive into these streams of research, we situate the immersive Cooperative Work Environment approach within the larger CSCW research agenda on Collaborative Virtual Environments and Common Information Spaces.

2.1 Immersive Cooperative Work Environments

The immersive Cooperative Work Environment approach derives from prior research in CSCW on Collaborative Virtual Environments and Common Information Spaces; however, there are distinct differences between them. Collaborative Virtual Environments designed to support real-time collaboration and interaction where objects and artefacts play core roles (Hindmarsh et al., 2000).

> [Collaborative Virtual Environments are] the shared space [that] defines a consistent and common spatial frame of reference. In other words, there is a well established co-ordinate system in which the relative positions and orientations of different objects can be measured. This is then combined with support for independent viewpoints which are represented through embodiments so that it is possible to infer where someone is attending and what they are seeing

> from their representation (note that making such an inference is not the same as actually seeing what they are seeing). Finally, CVEs aim to provide an integrated, explicit and persistent context for co-operation which combines both the participants and their information into a common display space (in contrast to multimedia systems which typically display communication and data in separate windows). Furthermore, the possibility of including a wide variety of data representations creates the potential to support a broad range of co-operative applications such as training, visualization, simulation, design and entertainment. (Benford et al., 1996, p.78)

The conceptual structure of Collaborative Virtual Environments is the design of environments that support cooperative work by providing a common spatial frame of reference for collaboration. In organizational settings, Collaborative Virtual Environments can take the form of video conferencing or desktop applications (Benford et al., 1996), but they are *not* limited to organizational settings or work practices per se but include support for, e.g., entertainment. In organizational settings, Collaborative Virtual Environments are similar to Common Information Spaces. Both are constituted by cooperative actors who are able to make sense of various types of information grounded in a shared context (Bannon et al., 1997). This context might take different forms depending on whether the cooperative actors are collocated and thus inhabit the same physical space or are geographically distributed, requiring additional efforts of articulation work when engaging in cooperation. Articulation work is the extra work required when more than one person needs to coordinate activities to solve a shared task (Schmidt et al., 1992; Strauss, 1988).

Collaborative Virtual Environment and Common Information Space technologies are thus both designed to support cooperative work activities. Both use digital means to support the creation of a shared work context, which actors use to make sense of information and input solving the shared task at hand. Despite the similarities between the two, fundamental differences exist. Whereas Common Information Spaces can be designed to support both asynchronous and synchronous interaction, Collaborative Virtual Environments are specifically dedicated to synchronous interaction. Further, Common Information Space research is mostly concerned with the workplace, whereas Collaborative Virtual Environment research does not take place in a work setting but instead focuses on interaction outside the workplace, such as in gaming or public performances (Benford et al., 1996).

Using VR technology to design Collaborative Virtual Environments for synchronous interaction *outside* the work setting is not new (Benford et al., 2002; Otto et al., 2006), whereas it is rarely used to design Common Information Spaces, where most systems address concrete organizational work settings and often use available organizational technologies such as electronic whiteboards or desktop systems (Bjørn et al., 2011; Bossen, 2002; Scupelli et al., 2010; Tang et al., 2008).

Our interest is in using VR technology to design an *Immersive Cooperative Work Environment* that provides a synchronous cooperative experience whereby participants experience real-life cooperative work situations. Thus, our research interest is related to the conceptual understanding of Common Information Space due to the focus on the *workplace*; but, unlike prior research on Common Information Spaces, we are not interested in designing organizational technologies to reduce the effort of articulation work in the workplace (Bossen, 2002). Instead, our aim is to design an immersive Cooperative Work Environment as a VR performance that *illustrates, demonstrates, and visualizes* the articulation work required in professional work practices as related to a particular building. The overall purpose of this environment is to allow participants to experience how their cooperative activities – including work and articulation work – are constrained or enabled by the building.

To mark the distinction between prior research on Collaborative Virtual Environments (e.g. Benford et al., 1996) and Common Information Spaces (e.g. Bannon et al., 1997), we introduce the *immersive Cooperative Work Environment* approach. We focus on the 'W' – the *Work* – and how we seek to design VR experiences where people's *cooperative work arrangement,* e.g., solving a shared work task in a specific work setting, is at the centre of the design.

2.2 Cooperative characteristics of immersive Cooperative Work Environments

Cooperative work exists in situations where multiple participants are *mutually dependent* upon each other to solve a shared task and are required to engage in *articulation work* (Schmidt et al., 1992). This interdependence is the core of the very definition of cooperative work. To have a cooperative work situation, at least two people need to depend upon each other to solve a shared task, and in such situations the need for articulation work arises. Referring to the work of Gerson, Star, and Strauss (Gerson et al., 1986; Strauss et al., 1985), Schmidt and Bannon (Schmidt et al., 1992, p.14) define articulation work as all the extra work required when multiple people need to "*articulate* (divide, allocate, coordinate, schedule, mesh, interrelate, etc.) their distributed individual activities". When actors are engaged in cooperative work, they must, in addition to their individual activities, engage in articulation work – extra work. The justification for this overhead and cost of articulation work is that the shared task cannot be solved by one single individual (*Ibid*), and that it is *this* overhead – *this effort* invested in articulation work – that cooperative technologies seek to support (Abraham et al., 2013; Andersen et al., 2011; Boden et al., 2014; Grinter, 1996). Thus, when designing immersive Cooperative Work Environments, we need to identify a shared cooperative task and find ways to design this task in the VR environment to simulate the articulation work required to solve this shared task that demonstrates the interdependence of work.

From prior CSCW research, we know how people engaged in work and articulation work use different strategies to reduce the efforts of articulation work, such as *awareness* (e.g., Souza et al., 2011) and *grounding* (e.g., Clark et al., 1991). When designing the immersive Cooperative Work Environment, it is important to imitate the real-life work task and how cooperative actors would be allowed to engage in awareness and grounding activities when 'testing' the building construction. Designing for awareness (Benford et al., 1995; Heath et al., 1992) is fundamentally about finding ways to convey the sense of cooperative actors and their interdependent activities. Since the very cooperative situation we are creating is a synchronous activity, the design task is to create a VR experience that provides participants the same kind of workspace awareness (Gutwin et al., 2002) they would have access to in the real-life situation. Thus, we want to support the cooperative actors engaging in articulation work through awareness features such as displaying participants' position and orientation in the spatial design, allowing for others to monitor and act accordantly (Gross, 2013). We must find ways to design for peripheral awareness – allowing participants to 'see at a glance' who is present and what they do (Benford et al., 2001). The design of workspace awareness is about providing a common frame of reference, important in cooperative work and often referred to as creating common ground (e.g., Bjørn et al., 2014; Olson et al., 2000). Common ground is the moment-by-moment, up-to-date knowledge that cooperative actors share and know that they have in common. Common ground is established through grounding activities (Clark et al., 1991). Grounding activities refer to the effort that people expend in creating grounding references (as in pointing to certain artefacts conveying information) or, in general, through various visual cues (Gergle et al., 2004).

Summarizing, the cooperative characteristics we are to include when designing immersive Cooperative Work Environments are interdependence, articulation work, awareness, and grounding. Further, prior work points to the importance of temporal ordering in cooperative engagement (Bødker et al., 2013; Orlikowski et al., 2002). Temporal ordering in cooperative work can take different forms, e.g., the temporal ordering in communication structured in conversation sequences (Clark et al., 1991), or the sequential flow embedded in formal constructs stipulating scripted practices supporting actors in predicting each other's actions and acting accordantly (Schmidt, 1997). Thus, when identifying the important design dimensions for creating immersive cooperative work environments simulating professional cooperative work, we must explore how participants enact temporal ordering as part of their cooperative experiences to ensure that the design supports the open-endedness of temporal ordering.

2.3 Professional work characteristics for immersive Cooperative Work Environments

Cooperative work comprises articulation work *and work* – professional work. In our case professional work is the work that takes place within hospitals. Immersive Cooperative Work Environments must include both articulation work *and* work in their very design. There is no 'a priori' in a VR simulation; instead, everything needs to be designed and implemented. The professional work relevant for the design of hospitals is healthcare work. This means that we need to consider how to design and implement professional healthcare into the immersive Cooperative Work Environment.

Professional *artefacts* are vital to hospital work, and, as former ethnographic research has demonstrated, artefacts can serve as formal and informal constructs supporting coordination (Bjørn et al., 2011; Schmidt et al., 1996; Symon et al., 1996; Wong et al., 2009). Artefacts in hospitals include chart racks, whiteboards, documents, etc., all serving to support healthcare professionals in distributing, dividing, and adjusting resources while having up-to-the-moment information on the current state of the hospital. Besides the coordinative artefacts, other artefacts in hospitals are essential for professional work. These include medical machinery such as ventilators, heart monitors, or blood pressure measurement machines as well as the professional use of such artefacts. Not only do we need to make digital twins of all these artefacts as part of the immersive Cooperative Work Environment – we also need to consider their location in the hospital and how they move around within the hospital.

Professional work includes specific *work practices* based upon specific organizational *policies.* People and artefacts do not simply move around in the hospital – they move around in a certain way. Formal workflows are organizational ways to engage in certain tasks. Workflows in hospital are often based upon medical and clinical protocols for solving specific tasks. Such tasks and policies include ensuring patient safety, diagnostics, or treatment, and policies can vary across hospitals, regions, or countries. For example, the medical protocol for assessing the urgency of patients arriving in a paediatric emergency department might vary from that in adult emergency departments (Bjørn et al., 2009). Besides medical workflows, there are also coordinative workflows, which are less situated in medical and clinical guidelines, e.g., cleaning, but still intertwined with organizational policies. CSCW research has proved that although workflows (medical or coordinative) are important for hospital work, they do not fully determine how work is accomplished. Workflows are not the same as the *flow of work* (Randall et al., 2007), as is evident in bed management in hospitals (Clarke et al., 2006). Flow of work comprises patterns and processes of work and includes *professional language*, which allows professionals to engage in fast and specific communication. The specific communication depends upon a shared meaning context (Bjørn et al., 2009), which serves as a basis for the continuous grounding activities developing the professional language. Thus, in designing immersive Cooperative Work Environments, we need to consider how to support participants' professional and coordinative workflows while allowing for open-ended and situated actions (Suchman, 1987), where participants can enact their professional language in an open-ended flow of work while engaging with artefacts.

Summarizing, the professional work characteristics relevant to the design of immersive Cooperative Work Environments include considerations of work practices, policies, artefacts, and professional language. Further, the temporal flow embedded in work practices, policies, artefacts, and language also influences how the temporal flow gets constituted. Thus, when identifying the important design dimensions for creating immersive cooperative work environments, we must explore how the temporal orientation gets displayed in participants' professional interactions in the immersive Cooperative Work Environment.

2.4 Spatiotemporal characteristics of the immersive Cooperative Work Environment

When designing an immersive Cooperative Work Environment, the conceptual understanding of space and place becomes pertinent. The much-quoted catchphrase "space is the opportunity; place is the understood reality" (Harrison et al., 1996) distinguishes between the geographical and mathematical features of a space (Dourish, 2006), and then between the social and cultural situatedness which makes a place.

> Physically, a place is a space which is invested with understandings of behavioral appropriateness, cultural expectations, and so forth. We are located in "space", but we act in "place". Furthermore, "places" are spaces that are valued. The distinction is rather like that between a "house" and a "home"; a house might keep out the wind and the rain, but a home is where we live. (Harrison et al., 1996, p.69)

The distinction between space and place is much debated (Ciolfi et al., 2008), and the distinctive difference is not clear-cut. Space is not just a geographical and mathematical location, since most geographical locations cannot be understood outside the cultural productions which made the space (Dourish, 2006; Harrison et al., 1996). We cannot understand the geographical location of Northern Ireland, South Africa, or Palestine without the political history which made these spaces, since politically contested geographical areas cannot be comprehended without their associated cultural societal backgrounds (Bjørn et al., 2018). Space emerges through social production. Still, the space-place distinction is a useful division for separating location (space) from activities (place). Immersive Cooperative Work Environments based upon VR technology are clearly social constructions, since the mathematical models that make the 3D representation are all digitally created and do not exist without the design work and implementation skills of the people building them. However, the ways in which the *social production of the* immersive Cooperative Work Environment *is designed* and the *social production of how the* immersive Cooperative Work Environment *is used* serve as clearly marked boundaries between the *immersive space* (as in the 'architectural 3D models') and the *immersive place* (which emerge when people occupy the VR simulation for the purpose of engaging in hospital work). *Loci* has been suggested as a term to describe the space-place that exists prior to the place creation (Harrison et al., 2008). Loci is constituted by the meaning-making processes that constitute places, and includes objects and artefacts; however, a place is more than a loci, as it entails a semantic tangle including people and events (Ibid). Thus, when designing immersive Cooperative Work Environments using VR technology, we are conceptually designing a loci.

Hospital work has been the focus of many CSCW ethnographic studies (Andersen et al., 2019; Bansler et al., 2016; Bjørn et al., 2007; Heath et al., 2002). Such work is by nature *mobile*; thus, when we are 'testing' a hospital building we must consider how people, patients, and artefacts move around. Healthcare professionals and patients move between departments (e.g. from the emergency department to the in-patient wards), treatment facilities (e.g. suture room or dialysis room), or examination rooms (e.g. medical imaging such as x-ray or MRI) (Ellingsen et al., 2003; Fitzpatrick et al., 2013; Mentis, 2017; Sarcevic et al., 2011). Mobility is thus an important feature of hospital work, and when we design an immersive Cooperative Work Environment simulating hospital work we must ensure that the cooperative task includes mobility, allowing participants to experience the building while moving. When we choose which tasks to embed within the immersive Cooperative Work Environment, we must find those requiring mobility of people and artefacts across and between locations in the hospital.

CSCW research has documented in detail how the *spatial layout* in hospitals at times enables or constrains the work of healthcare professionals as they move around in the available space (Balka et al., 2008; Bardram et al., 2005; Møller et al., 2017; Møller et al., 2012; Tellioglu et al., 2001). Hospitals as domain-specific buildings need to provide the best possible conditions for healthcare professionals to cooperate and move around when treating patients. Spatial layout is thus critical to hospital function (Bardram et al., 2005). Decisions about spatial layout have a direct impact on the work as well as on the use of digital healthcare information systems (Balka et al., 2008). If the time it takes for a cardiac team to run from their stations to a trauma patient in the emergency department is too long to save that patient (Bjørn et al., 2008; Soar et al., 2015), the architectural layout seriously constrains the professional activities. This means that when we design a hospital building, we must understand the temporal patterns and mobility embedded in the work that will take place within the hospital. Temporal patterns and coordination are fundamental for hospital work (Egger et al., 1992; Møller et al., 2011; Reddy et al., 2002), and when work is mobile, the relationships between artefacts and places can be considered portable places, where the location and movement of healthcare professionals and artefacts, e.g. documents, act to demarcate communication and coordination activities (Østerlund, 2008). It is the design of the healthcare activities that transforms the VR simulation of a hospital from merely a 3D mathematical space into a place of cooperative activities.

Summarizing, the *immersive space* in the immersive Cooperative Work Environment is produced through the configurations and implementation of BIM and VR technology; and the *immersive place* is enacted when healthcare professionals put on the VR headsets, enter the virtual architectural models, and begin to interact cooperatively. However, it is essential to acknowledge that the social production of space and place are two intertwined activities highly dependent upon each other, and seamlessly interrelated in practice. Put simply, if we are to successfully design immersive Cooperative Work Environments, we must create conditions for participants to engage in mutually dependent place-based activities (the cooperative characteristics), producing the social engagement embedded in the professional work (the professional work characteristics) – all in relation to the spatiotemporal characteristics of loci and mobility. Finally, in identifying the design dimensions relevant for the immersive Cooperative Work Environment, we must explore how participants manage to enact temporal orientation in the spatiotemporal experience.

3 Method

Before designing and implementing the immersive Cooperative Work Environment, we need to identify a relevant work practice that suits our purpose and aim. We are not only modelling the architectural building in the VR setup; we are also modelling relevant professional work practices that will take place within the building. To identify such practices, ethnographic work informing the design of the immersive Cooperative Work Environment is crucial.

Since 2015, we have studied two 10-year architectural hospital projects: the *New North Zealand Hospital* and the *New Bispebjerg Hospital*. These projects are part of a large initiative in Denmark, whose government strategised to reduce the number of small hospitals and to instead build a few so-called super hospitals to ensure the best treatment through critical mass of expertise. The main idea is to have fewer, larger, and more specialized medical departments by collocating medical expertise.

Prior to our work on immersive Cooperative Work Environments, one of the authors had ethnographically investigated the role of BIM technology in hospital design from different perspectives in the two hospitals (Møller et al., 2017). While we in this paper focus on New North Zealand Hospital, our work at New Bispebjerg Hospital shaped the work presented here in important ways. For example, that work allowed us to closely analyse physical simulations using mock-ups of patient rooms to identify appropriate workflows for the design of the work practices in the immersive Cooperative Work Environment.

The New North Zealand Hospital project is one of the government's new super hospitals. The large hospital construction project aims to extend and refurbish an existing general hospital located in Copenhagen, Denmark. The project involves the design and construction of a new main hospital building of 118,000[1] m^2 and the refurbishment of 12,000 m^2 of the existing buildings. The new hospital will serve approximately 500.000 patients.

Figure 1: Concept illustration of the new hospital (outside): https://www.regionh.dk/nythospitalnordsjaelland/til-pressen/presserum/Sider/Billeder-Pictures.aspx

During the first years of the study, one of the authors ethnographically investigated the hospital projects, spending more than 150 hours in ethnographic observations and joining

[1] https://www.regionh.dk/nythospitalnordsjaelland/derfor-bygger-vi/FAQ/Sider/Hvad-skal-hospitalet-rumme.aspx

multiple workshops, meetings, and activities. She engaged with participants from the architectural firm, their client organization, the hospital organization, and the project consortium, as well as with BIM consultants and client advisors. Data collection activities included participating in review sessions of different types of architectural plans onsite and with hospital representatives. In addition, she conducted multiple interviews with consultants, architects, and healthcare professionals. The overall research interest was to understand the architectural practices and the use of 3D models and BIM technology in the client organization. Thus, until December 2017, our work with the hospital projects was predominately ethnographic study (Blomberg et al., 2013; Randall et al., 2007). In December 2017, we began moving from study to design – and although the design work was based on important insights from the ethnographic field studies, we had a clear shift in focus. By working closely with the hospital and architects, we gained access to the 3D computational models of the future hospital, and these served as the fundamental infrastructure for our design work towards the immersive Cooperative Work Environment.

3.1 The Cooperative Work: Advanced Life Support

Designing an immersive Cooperative Work Environment required us to identify a concrete cooperative work practice to serve as the focus for the design. Previously, one author had ethnographically observed ALS simulations at New Hospital Bispebjerg, both in the use of mock-up[2] and as part of the simulation and education laboratory, *Copenhagen Academy for Medical Education and Simulation* (CAMES). By combining these insights, re-visiting the education laboratory CAMES, and organizing new visits to the company, Laerdal, who provide medical training products for lifesaving and emergency medical care, we decided to focus on ALS. It is important that the type of work in focus be suitable for the design of a cooperative work task to be implemented in the immersive Cooperative Work Environment. We needed a compartmentalized medical professional cooperative task that we could model and implement in our immersive Cooperative Work Environment and that allowed the end-users a collaborative experience in an open-ended cooperative situation.

ALS requires multiple people to be engaged in a shared cooperative task while using artefacts and includes mobile work of people and artefacts. By choosing the standardized cooperative work procedure for ALS, we chose a work practice that must be accommodated in all hospital designs. ALS is a medically designed workflow, taught to all healthcare practitioners (doctors, nurses, etc.) in Denmark as part of their professional training. The ALS workflow stipulates how healthcare practitioners are to interact and collaborate during a resuscitation attempt on a patient suffering cardiac arrest (Soar et al., 2015).

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2 https://www.bispebjerghospital.dk/nythospital/nyt-og-presse/nyheder/2017/Sider/Er-der-plads-til-at-redde-liv-i-den-nye-sengestue.aspx

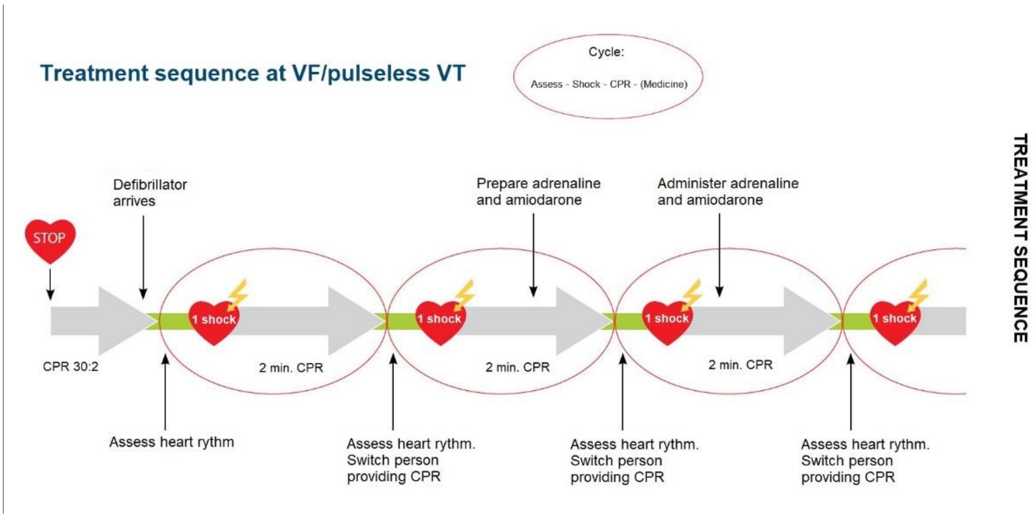


Figure 2: Procedure overview for the ALS protocol (translated from a Danish cardiac arrest pamphlet)

What makes the ALS protocol (see Figure 2) excellent for our purpose is that it entails clearly scripted sequential tasks to be done while producing clearly defined dependencies between the various healthcare professionals involved. Thus, we designed and implemented the ALS as exemplary of the professional language, procedures, and artefacts to be accommodated in the future hospital. We based our design of the ALS workflow on our ethnographic study and on our document analysis of the medical protocol descriptions, and on visits to CAMES and the training equipment manufacturer, Laerdal. Further, we made several onsite visits to the North Zealand Hospital. We then analysed the ALS protocol in practice using video documentation from the training centre. These empirical investigations allowed us to learn in detail the process as well as the artefacts used for ALS.

3.2 Implementing ALS in the Immersive Cooperative Work Environment

We designed and implemented two ALS scenarios: one where the patient is collapsed on the bed in their room, and one where the patient is collapsed in the bathroom of their room. We implemented two fully functional avatars of different genders, where movement mimicked the user's movements. Finally, we implemented 11 digital artefacts and artefact types: ventilation mask, oxygen outtake, beds, patient doll, defibrillator, doors, stools, bedside tables, resting chairs, wall clocks, and a cardiac alert button, at a 1:1 scale in the BIM 3D model. Each was based on real-life counterparts, identified during empirical visits in the field. The complete set of artefacts had the same size, weight, and mobility as the physical counterparts on which they were modelled.

For the implementation, we used the HTC Vive Head-Mounted Display (HMD) Virtual Reality technology with standard controllers, and the Unity game engine using the native SteamVR asset, which makes VR plug-and-play scenes possible. The SteamVR asset does not provide many "out-of-the-box" interaction-and-movement mechanics; thus, we included the VRTK (Virtual Reality Tool Kit) asset library for interaction and movement mechanics. For networking features, we used the built-in UNet framework in Unity.

When developing our scenarios, it was important to consider how to demonstrate the socio-material nature of the diverse artefacts. We wanted to design these artefacts as being open to the unanticipated material consequences that would arise during the immersive experience. Each artefact cannot be comprehended as a single entity but must include its relationships across multiple artefacts, locations, and movements (Bjørn et al., 2014). This means that it was important for us to consider the context in which the scenarios unfold; how artefacts are related to other artefacts; how artefacts become related to locations; and, finally, how artefacts are related to movement. Learning from designers of patient training dolls (used in traditional ALS simulations), we carefully designed our VR training doll to mimic the urgency of ALS – i.e. pulse and breathing (see Figure 3).

For all artefacts and spatial layout, we used the game engine to implement physics such as gravity and weight, as well as surface, making all interactions as bound to the material matter of the 3D models as they would be in the physical world. For example, participants must open closed doors to enter rooms, and walking between locations was implemented to take the same amount of time that it would take to walk the distance in the physical world.

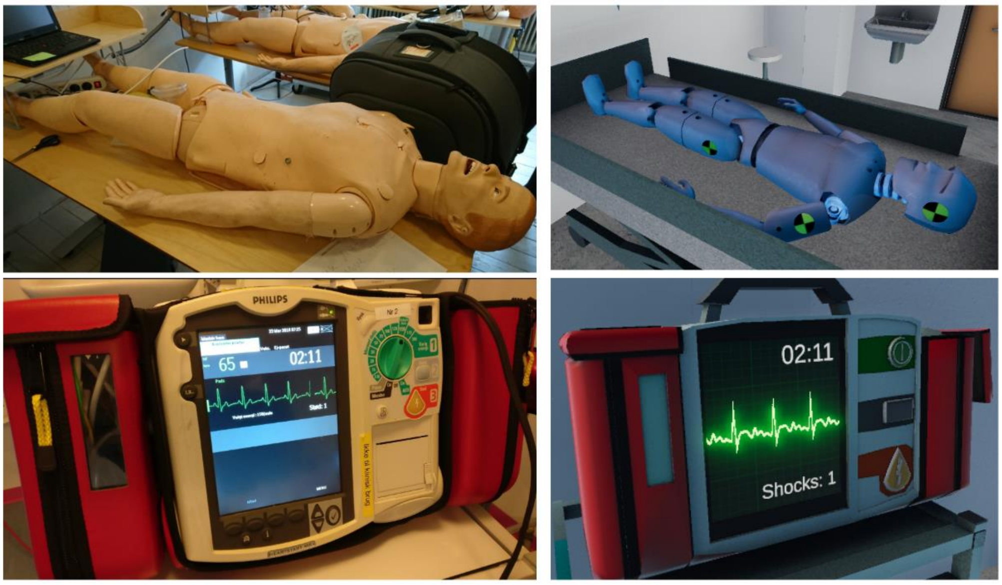


Figure 3: Illustration of the physical artefacts: patient doll and defibrillator compared with the VR implementations.

Because the entire 3D BIM model of the hospital was immense (around 115.800 m^2 of floor area), we removed the areas of the hospital that were not immediately required for our scenarios. Because the two upper floors are primarily used as patient wards, we chose one section of the third upper floor (see Figure 4), which also contained the preliminary location of the defibrillator artefact in the BIM model. The defibrillator is a core artefact in the ALS medical protocol. Although cardiac arrest can take place anywhere in the hospital, the location with the highest risks of cardiac arrest is the patient rooms. Thus, the patient room became the core location for our scenarios.

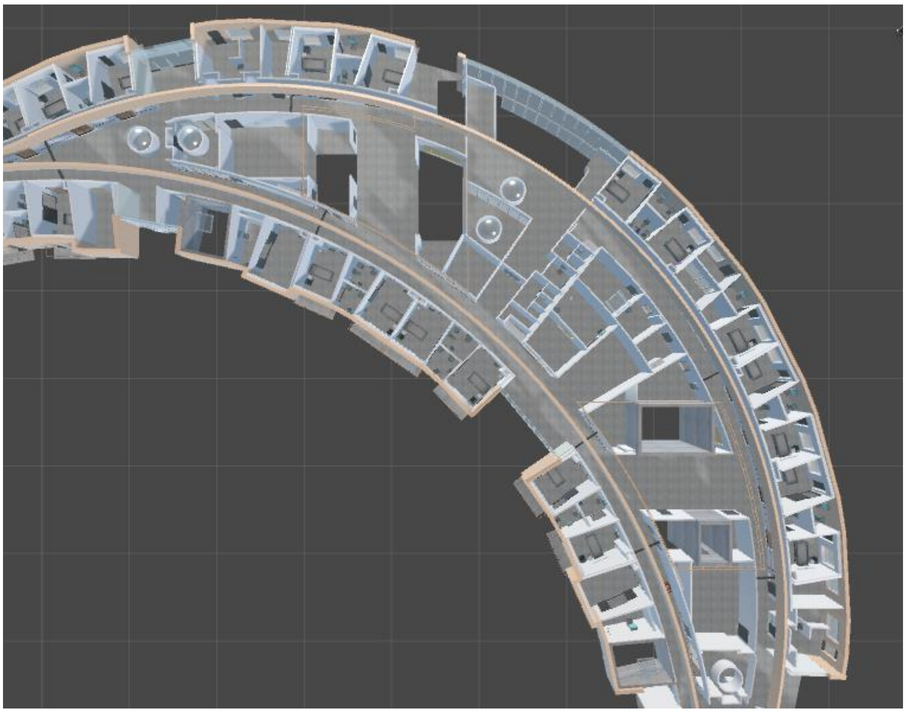


Figure 4: Bird's-eye view of the VR prototype with the roof removed: the patient ward on the third floor.

3.3 Movement in the immersive Cooperative Work Environment

We implemented two types of locomotion techniques to mimic the average human movement velocity of real-life, smooth and arm-swinging locomotion. The latter is used to reduce the risk of "VR sickness". The symptoms of VR sickness resemble those of motion sickness (LaViola Jr, 2000). These include nausea, dizziness, and headache, and are most likely to occur when using locomotion techniques where the physical sensation of the real body and the perceived movement of the virtual body do not align. Once the user experiences VR sickness, the recovery time is often 30 minutes (Tanaka et al., 2004).

Smooth locomotion: When either resting a finger on or pressing down on the trackpad, on the left controller, the player will move in the direction of the position of the finger on the trackpad relative to the head position in the virtual environment. *Arm-swinging locomotion*: The locomotion techniques rely upon real body movement, such as marching in place, which has been found to prevent VR sickness (Lee et al., 2017). When arm-swinging locomotion is enabled, the player can press down on one or both trackpads and then swing the arms as when walking or running in the real world for stability. The movement speed is determined by the speed of the arm swings. If any of our participants were prone to or began experiencing VR sickness, we encouraged them to use the arm-swinging locomotion.

3.4 Data Collection

We recruited 13 healthcare professionals to explore the future architectural design of the hospital using our immersive Cooperative Work Environment. All participants knew the ALS medical protocol prior to the experience, and it was completely up to them to figure out how to coordinate the resurrection attempt and make use of the available artefacts.

During the period May 23–June 1, 2018, we set up 10 empirical sessions, nine in a hospital and one in a nursing school. Each session lasted 90 minutes and had two participants, at least one of whom was a healthcare professional. After an introduction to the study, the session began with a short sandbox scene (test environment exploring the VR technology), where participants were able to interact with the virtual artefacts and become familiar with the locomotion techniques.

Each pair of participants was randomly assigned one of two scenarios: bed or bathroom. The nine sessions took place at the current North Zealand Hospital, and all sessions included participants who are expected to work at the new hospital when finished in 2022. The 90 minutes included the introduction, the actual experience of the immersive Cooperative Work Environment, and a post-interview.

All sessions were video-recorded using both an external camera and a screen capture of participants' *virtual point of view* (VPOV). The three data sources were connected into one video stream, which was used in the post-interviews. Of the 10 sessions, seven included one healthcare practitioner and a researcher, and three included two healthcare practitioners simultaneously. In the sessions where the researcher participated, the healthcare practitioner would take the lead and the researcher would follow verbal or bodily expressed instructions. When two healthcare professionals were participating together, the post-interviews were conducted as a group interview; in the other sessions, post-interviews were individual.

During the post-interview, participants were encouraged to narrate what they were doing on the video stream, as a way to articulate the context for their activities. Having participants narrate while watching their video stream from the three different sources allowed them to *talk aloud* (Hartson et al., 2012) as they re-experience their interaction, providing us empirical details not available through observation, however crucial to understanding their experiences. Below is the schedule for the sessions (see Table 1).

Test ID	**Occupation**	**Name**	**Date**	**Scenario**	**Scenario time**	**Post-interview time**
1	Nurse student	Louise	23/05-18	Bathroom	6.55 min	25.50 min
	Nurse student	Karoline				
2	Paramedic	Susanne	28/05-18	Bathroom	10.44 min	23.24 min
	Researcher	Mark				
3	Cardiac coordinator	Laura	28/05-18	Bed	3.03 min	6.28 min
	Researcher	Mark				
4	Nurse anesthetist	Dorthe	29/05-18	Bed	8.41 min	22.59 min
	Researcher	Mark				
5	Nurse anesthetist	Sidsel	29/05-18	Bathroom	7.56 min	21.20 min
	Researcher	Mark				
6	Nurse	Julie		Bed	9.21 min	19.33 min

	Researcher	Mark	30/05-18			
7	Cardiac nurse	Anja	30/05-18	Bathroom	9.23 min	17.06 min
	Cardiac nurse	Ida				
8	Cardiac nurse	Joan	31/05-18	Bed	7.27 min	14.19 min
	Researcher	Mark				
9	Cardiac nurse	Mie	31/05-18	Bathroom	6.15 min	10.38 min
	Cardiac nurse	Marianne				
10	Doctor	Annemette	01/06-18	Bathroom	6.56 min	25.36 min
	Researcher	Mark				

Table 1: Overview of the 10 sessions and participants. All study participants were assigned pseudonyms to protect their identity.

3.5 Data Analysis

We collected 264.54 minutes of video data: 77.41 minutes displaying scenarios, and 187.13 minutes displaying post-interviews. All video material was uploaded to NVivo 11 for analysis.

The analytical process was structured by the two first authors reviewing the initial video material to detect interesting and surprising themes. These results were then discussed among all authors. Together, we identified important topics and concepts, which informed the continuing video analysis, where the two first authors reviewed the complete dataset iteratively. During this analytical process, all authors meet weekly to discuss new insights, progress, and any new surprising findings and the latest results.

This iterative analytical process was informed by theoretical interests from the literature and was particularly inspired by early CSCW video analysis of ethnographic work (Heath et al., 2002; Heath et al., 1992; Luff et al., 2012). The complete video material from the scenarios was annotated into sequences based on scenarios (bathroom or bed) and post-interviews (both group and individual). As the analytical process matured, annotations included theoretical CSCW concepts such as awareness (Gutwin et al., 2002), coordination (Gerson, 2008), and articulation work (Schmidt et al., 1992) – as well as more descriptive empirical categories such as 'arm gestures' and 'direction'. When interpreting specific video sequences, data was triangulated between the post-interviews, the virtual point-of-view of the VR-ALS scenario, and the external camera capturing participants' actual movements. We paid close attention to each little movement and interaction and compared these with the motions and sounds of the scene. Thus, we were able to investigate how cooperative partners monitored each other and acted accordingly. Our focus was on understanding their collaborative activities, including their artefact manipulations, amplified by the spatial arrangement, and thereby unpacking how participants increased their awareness between actors when interacting with common objects in the virtual building (Benford et al., 1997).

4 Results

Looking across all our empirical sessions, it was evident that participants found that the immersive Cooperative Work Environment allowed them to experience how the spatial layout shaped their abilities to conduct the ALS protocol as a cooperative task in the future hospital. Several participants expressed in the post-interviews that they were surprised about the immenseness of the Cooperative Work Environment:

> It was awesome to experience spaciousness and feel that you were inside of it [the hospital] […] and then there are the distances [stretches arms up like trying to illustrate the unconfined space] and feel the open space. You tend to forget where you are. Which felt pretty realistic. (Test ID: 1, Louise (Nurse student) & Karoline (Nurse student), Bathroom scenario)

> I think it was a good experience. I am actually very positive, where I am thinking, this could enhance the quality. Because luckily, we don't experience cardiac arrest that often anymore. But this also means we have to look for alternative methods of training these situations, so when we experience an incident, then we need to know what to do. (Test ID: 5, Sidsel (Nurse anesthetist), Bathroom scenario)

The ALS scenarios turned out to be an important design feature of the immersive Cooperative Work Environment because they enabled participants to experience the architecture in relation to a concrete work situation. By building upon their existing knowledge of the ALS protocol, as well as the healthcare tradition of roleplaying when training, we were able to position the architectural layout at the periphery of attention while placing the work at the centre, while still gaining insights about the architecture. When people engage in cooperative activities, the physical space they occupy is not the centre of attention but rather serves as the taken-for-granted background condition allowing the cooperative activities to take place. We designed the immersive Cooperative Work Environment in a similar way by placing the cooperative work at the centre and the architectural design as the background infrastructure, which was instrumental in allowing participants to focus on their work and to recognize and pay attention to the architecture only when the physical surroundings interfered with their work practices. Such 'architectural breakdown situations' surface potential functional errors, which again could inform architectural design. Designing with the cooperative activities as the centre and the architectural design as the background became an important feature of the immersive Cooperative Work Environment. The spatial layout faded into the background, allowing participants to interact seamlessly, *unless* the spatial layout constrained the practices; then the physical surroundings would surface in the interaction and become a topic for discussion during the post-interviews.

4.1 Asymmetrical double-door problem

We did not manipulate the original 3D models of the hospital in our Cooperative Work Environment. All artefacts and objects in the hospital were modelled in the immersive Cooperative Work Environment exactly as they had been in the BIM model. Further, because we added physics, engaging with the 3D model required people to act similar to how they would act in the real world. This meant that to enter a door, one needed to first open it – and that pushing a bed required force relative to the weight of the bed.

The VR physics combined with the scenarios surfaced some important problems in the architectural design. In one of our ALS scenarios, participants would find the patient suffering cardiac arrest in the private bathroom of their patient room. The architectural design of the door, which leads into the patient room, is asymmetrical: the left side of the door is smaller than the right side (as seen from inside the patient room). This architectural design meant that if both doors were open, the large door to the right would cover a large part of the entrance to the patient bathroom, making it difficult to discover the patient (see Figure 5).

(a) The double-door entrance as seen from inside of the patient room. Here the double-door is closed.

(b) The double-door entrance as seen from inside of the patient room. Here the double-door is open and is seen obstructing the entrance to the bathroom for people and artefacts to pass through.

Figure 5: The double-door architectural design in the BIM model as it appeared in our VR setup.

Note that we did not create this design: it was an existing feature of the architectural design of the patient rooms. In our empirical sessions, half the participants experienced the bathroom scenario. In all sessions, participants identified the asymmetrical double-door design as either annoying, disruptive, or troublesome – and, in all cases, they expressed these problems through their experience of being able to accomplish the ALS protocol appropriately. This was further documented through the video recordings, where it was evident that participants engaged in the bathroom scenario spent more time locating the patient when they entered the patient's room initially. Participants would first scout the whole area around the bed, and only later check the bathroom because they could not find the patient. If the asymmetrical door had not blocked participants' line of sight, they would have been able to see directly into the bathroom and spot the patient immediately. As Annemette described her experience during her post-interview:

> I'm thinking, is the patient lying behind the bed? Where is he? I end up walking past too quickly, so I don't notice that there something behind the door. I then figure out that there is this bathroom in the corner behind the door that I entered through. So it is kind of hidden when you enter the room. So I think, if the door had been on the other side and opened in the opposite direction, then I would have been able to look directly into the bathroom, and then I would have been able to spot the patient earlier. (Test ID: 10, Annemette (Doctor), Bathroom scenario)

It was *not only* during the initial part of the scenario that the asymmetrical double-door was problematic. The door design constrained cooperative engagement during the complete ALS protocol. After locating the patient, participants had to close the larger door in order to enter the bathroom. However, a crucial part of ALS is retrieving equipment; thus, participants had to open the door in order to enter the hallway, locate equipment, and then return to the patient. The large door would continuously block the entrance to the bathroom, requiring additional time to open and close the door. In the post-interview, Susanne explained:

> Yes. I'm closing the door because I could not get past it. It opened up towards the bathroom, so to create more space, I had to close the door … This is a design-related matter about the hospital and it is inappropriate that the doors open like that, and that it should instead open in the opposite direction. (Test ID: 2, Susanne (Paramedic), Bathroom scenario)

Although our immersive Cooperative Work Environment was designed for two participants, several participants explained how the problem would increase in a real-life situation during their post-interviews. They explained how the ALS protocol normally includes 8 to 10 people; thus, multiple people would be entering or leaving the room for different reasons at different times – each time requiring participants to open and close the door. Because people are in a hurry when it comes to cardiac arrest, the door also produced a high risk of injury for the healthcare practitioners, as they might accidentally push the door into someone located on the floor next to the patient providing CPR. In the post-interview with Anja and Ida, Anja explained:

> Now that we are working here standing, we have set the defibrillator up outside the bathroom, and this is before the cardiac arrest team would normally arrive. But then the entire anesthesia team and others come running, and they would risk slamming the door into us while we are working – this would be the case in a case like this. (Test ID: 7, Anja (Cardiac nurse) & Ida (Cardiac nurse), Bathroom scenario)

Clearly, the architectural insights that surfaced during the ALS scenarios with the bathroom concerning the asymmetrical doors were an important architectural issue concerning all the participants who experienced the bathroom scenario. The issue never surfaced in the ALS scenarios in which the patient was located in the bed.

4.2 Orientation in the Immersive Cooperative Work Environment

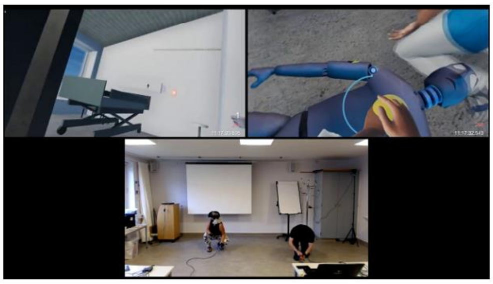
As we know from the literature, orientation in immersive environments is a challenge, and in our design we tried to accommodate the orientation challenge using known design strategies for presences and awareness, e.g. considering the design of virtual bodies, gestures, and locations. However, interestingly, it turned out that *orientation is also temporal* in the immersive Cooperative Work Environment – and this type of temporal orientation was critical for the experience of the architecture.

We found that three different types of temporal orientation were essential to our immersive Cooperative Work Environment: (1) *Clock Time*: how much time has passed since the activity was initiated, (2) *Action Time*: the time it takes to perform particular sub-activities, and (3) *Sequential Time*: the time required when actions are performed sequentially and in a certain order. These were essential because they allowed participants to navigate and orient their actions in relation to the professional, cooperative, and spatiotemporal aspects of the design. Below we demonstrate each in turn, while explaining how they were essential for the participants to explore the architecture.

4.2.1 Clock Time. When performing the ALS protocol, actively tracking clock time is central, because saving patients experiencing cardiac arrest is a race against time. For each passing minute without intervention in the form of CPR, the patient's survival chance decreases by 10% (Perkins et al., 2015). Thus, knowing how many minutes have passed since the patient was discovered matters tremendously for the concrete work task. Furthermore, the ALS protocol is very stern regarding which tasks must be performed at specific moments at specific time intervals. To accommodate these temporal parts of the professional workflow, we made it possible for participants to track clock time in two ways: (1) by looking at an analog clock hanging on the wall above the door, and (2) by looking at a digital clock located on the front of the defibrillator artefact. The latter option was only possible when participants had retrieved the defibrillator from the hallway.

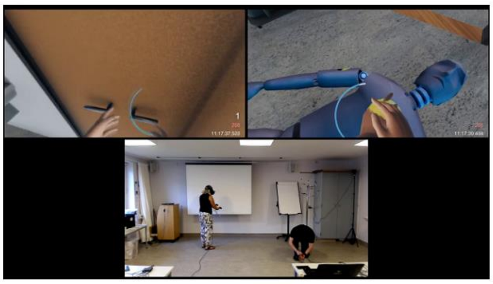
In all our empirical sessions, participants actively tracked the clock time, and this tracking was an essential part of the cooperative work arrangement. This was evident in all the recordings of both scenarios (bathroom and bed). Figure 6 is a video sequence demonstrating how Susanne (healthcare professional) and Mark (researcher) tracked clock time.

(a) Susanne asks Mark to start CPR, while she would go retrieve the equipment



(b) Susanne looks over her right shoulder to look for at clock above the patient bed

(c) After getting up and turning around to go to the door, she notices the clock above it and stops for a moment



(d) Afterwards, Susanne proceeds with her initial task of retrieving equipment

Figure 6: Susanne looks for the clock on her way to retrieving the equipment while Mark provides CPR.

Tracking clock time is critical to interpreting the current situation and status of ALS work. The video sequence in Figure 6 demonstrates how Susanne tracks the clock time after finding the patient experiencing cardiac arrest. As stipulated by the ALS protocol, Susanne directs Mark to initiate CPR, while she will retrieve the equipment. However, on leaving the room she orients herself by turning her head towards the clock hanging on the wall above the door. In the post-interview, Susanne further confirms this temporal orientation and explains how the ALS protocol requires a "time horizon" indication. This tells her how much time has passed since the discovery of the patient and in relation to the defibrillation cycle. Attempts at resuscitation might be futile if too much time has passed, and it is important to note such situations. Calling the time of death for patients under cardiac arrest is aligned with constantly monitoring clock time. In Figure 6, Susanne notes the clock time, not only because it is important at the moment but because it will be important in the near future. Because the defibrillator is not in the room yet, the wall clock is the only method of temporal orientation towards clock time. In other words, Susanne monitors the cooperative situation and sees that Mark is occupied with CPR on the bathroom floor, which means that he is unable to see the clock on the wall. She acts accordingly by monitoring the clock time and reprioritizing the available time for other tasks, e.g. going to get equipment. Susanne explained in the post-interview:

> I asked my colleague to start CPR and I am trying to look for a clock to see what time it is, so that I have an approximate... sort of 'time horizon' in terms of how far we are and how long we will have progressed. … I found it [the clock] after… right in the end [references Figure , frame c, on her way to the door]. (Test ID: 2, Susanne (Paramedic), Bathroom scenario)

When asked about reasons for tracking clock time, she explained:

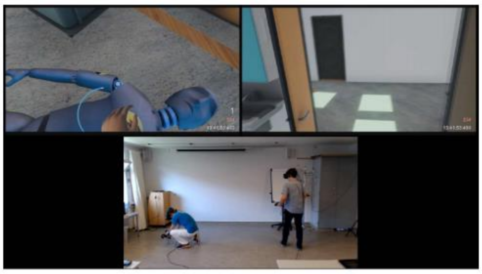
> Well, that is in relation to our cycle [a reference to defibrillation cycle (2 minutes between every shock)] and to know... If we have been trying for more than 30 minutes, then it might be pointless. Then we might want to consider stopping. (Test ID: 2, Susanne (Paramedic), Bathroom scenario)

What is evident in the above example is that the clock time was an important feature of the cooperative work task, giving the participants important information about clock time in relation to the location of others, their range of visibility (how Mark could not see the clock), and how these factors might change when people move around in the environment (seeing the clock as Susanne leaves the room). It was clear that what made clock time appropriate for the participants to experience the spatial layout of the patient room was their ability to perform temporal orientation, similar to how ALS is done in real life.

4.2.2 Action Time. In the immersive Cooperative Work Environment, we designed each activity in the scenario based upon the design guideline that the activity must take the 'same time' that the activity would take in the real world. Walking a distance in the immersive environment required the same amount of time as walking that same distance in real life. While the activity of performing CPR in the immersive environment was implemented as a simplification of the real-life activity, the action time of each sub-activity was enforced at all times. This was particularly relevant for the implementation of locomotion. Part of the scenario forces participants to retrieve critical equipment (defibrillator and ventilation artefacts), placed outside the patient's room and thus requiring participants to explore the spatial layout. Without teleporting as an option, participants experienced the time it took to retrieve the equipment as in a real-life scenario. This design decision had a significant impact on temporal orientation and thus on temporal coordination. The 'action time' it took to complete a task was mutually monitored by the cooperative participants in order to coordinate the cooperative workflow. This link between "real-life action time" and "Cooperative Work Environment action time" turned out to be crucial in the implementation of the scenario to support temporal orientation. This is evident in the video sequence in Figure 7.

(a) Sidsel checks the status of the patient while Mark is on standby. Sidsel states that the patient is under cardiac arrest.

(b) Sidsel looks at Mark, and utters "We need to call cardiac arrest, can you press...?", followed by Mark uttering "I'm pressing the cardiac arrest button." and presses the alarm button.



(c) After Mark has pressed the alarm, Sidsel utters "I'm going to start..." and starts to provide CPR, while Mark utters "I'm going to retrieve the equipment." acknowledged with a "Yes." from Sidsel.

Figure 7: Initial coordination of tasks: who stays and performs CPR, and who retrieves equipment.

The above example illustrates an empirical session, where Sidsel confirms that there is a patient with cardiac arrest lying on the floor. She asks Mark to activate the cardiac arrest alarm (placed next to the bed) and to fetch equipment while she stays with the patient to perform CPR. When asked in the post-interview how she made this decision, she explained:

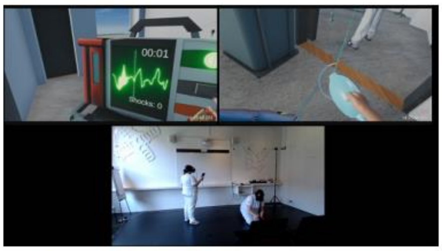
> Sidsel: "… you have to - it is ingrained within me. We need to continue the treatment, we need to follow the algorithm. One stays with the patient to provide heart massage, and then the other can run in the meantime when we do not have more hands."
> Mark asks: "So why did you stay to provide heart massage instead of …?"
> Sidsel interrupts and answers: "Because I was closest to the patient. Time is the worst enemy in this, and for each minute we reduce the chance of survival by 10%. So I was thinking that it would take too much time for me to get out of the bathroom, and get you into the bathroom. And then I was maybe also thinking in the back of my mind that you knew where to go. That made me think it was the most effective way to do it. (Test ID: 5, Sidsel (Nurse anesthetist), Bathroom scenario)

What is evident in this example is that the spatial layout and location of the avatars is essential information for the participants to make sense of the situation and to make decisions on coordination. Because Sidsel's avatar is in close proximity to the patient, she decides to stay in the bathroom and perform CPR while Mark retrieves equipment. In other words, Sidsel monitored her own proximity in relation to Mark's proximity to the patient. She takes this information into account when assessing the spatial layout and the time it will take to virtually leave the room, retrieve equipment, and then return to the patient's location. Thus, Sidsel acts according to her interpretation of the situation by making it audibly available to Mark that she will begin CPR while he retrieves equipment. Mark monitors and acts accordingly by leaving the patient's room to retrieve the ventilation mask and defibrillator. Accommodating action time was an important part of the implementation, as Sidsel explained when comparing the immersive Cooperative Work Environment with the simulation center for ALS training:

> […] I really think this could be a good supplement training method in the simulation center, if you are able to further develop it so that you can do the correct hand-grips [a reference to holding the ventilation mask on the patient's mouth]. I really think this can be useful. And particularly the part about who is retrieving equipment and who is staying. Because when you are in the simulation center, sometimes we just pretend it is just over here [picks up a water bottle moved it a bit away and takes it back again], or we are going for a needle insertion, then we just put some tape on the spot and pretend. I mean, different things could be more realistic in this [points at the computer in reference to the VR-ALS scenario], where things take the time it takes to do and can be difficult. (Test ID: 5, Sidsel (Nurse anesthetist), Bathroom scenario)

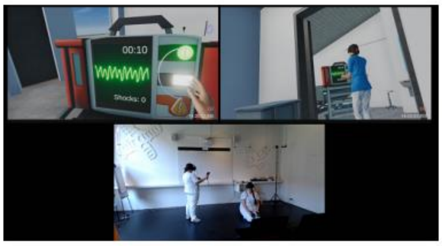
Action time was found to be essential in all sessions as a way to provide important insights on the temporal orientation in the immersive Cooperative Work Environment. Action time allowed participants insights which supported them in relating the scenario to the spatial layout as well as to their real-life experiences.

4.2.3 Sequential Time. The final aspect of temporal orientation that turned out to be critical for the immersive Cooperative Work Environment was sequential time. According to the formal guidelines for ALS, sub-actions must be performed in a specific order and at certain times. *Sequential time* for temporal orientation thus ties together the monitoring of *clock time* and *action time*. From action time, we know that performing tasks or moving around in the immersive Cooperative Work Environment was designed to take the same time as in the real-life scenario. Monitoring clock time allowed participants to know where they are in the current ALS process and thus to predict the next step. As in the real-life ALS protocol, the VR workflow requires participants to coordinate and distribute tasks across all who take part in saving the patient with cardiac arrest. While we wanted to design the scenario as a situated and open-ended cooperative situation, it was also important for the participants to train and organize their work related to a prescribed sequence. By making it possible for participants to follow the same sequential ordering in an open-ended cooperative situation, we allowed them to perform ALS according to the prescribed sequence (see Figure 8).

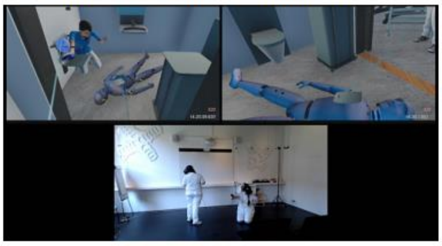


(a) Mie (left) is monitoring the defibrillator while Marianne (right) is providing CPR.

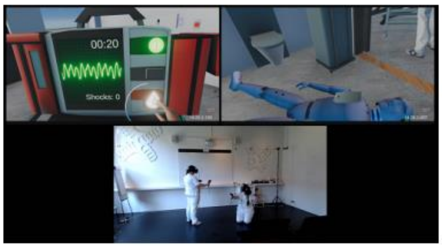
(b) Mie utters "Can you take a break for a moment? Rhythm check." while turning her head from the looking at the defibrillator to look at Marianne.



(c) Marianne pauses CPR, making it possible for Mie to monitor the patient's rhythm on the defibrillator. Mie monitors a shockable rhythm and utter "There is VT, I'm charging" while Marianne simultaneously continues CPR.



(d) Just before Mie presses the charging button, she utters "Can you remove the oxygen?". Marianne reacts immediately by removing the ventilation mask and moves away from the patient. Meanwhile, Mie turns her head towards Marianne to ensure that she did in fact remove the oxygen and no longer touches the patient.



(e) The defibrillator is now ready to shock, and Mie turns her attention back to the defibrillator. Mie utters "All away, oxygen away" and presses the shock button.

(f) Finally, Mie utters "Just continue CPR" while simultaneously turning her head to look at Marianne. Marianne starts providing CPR again.

Figure 8: Defibrillator shock.

In Figure 8, the different sequential activities involved in providing patients defibrillator shock are displayed. During defibrillator shock, it is vital that neither a human nor a ventilation mask is touching the patient. Meanwhile, the ALS guidelines stipulate that CPR must take place whenever the defibrillator is charging in order to reduce time without CPR, since CPR is imperative for survival. This means that it is key for the participant operating the defibrillator to ensure that other participants and ventilation masks are not in close proximity to the patient when the defibrillator is done charging and ready to shock. The above video sequence shows the moment where Mie, operating the defibrillator, orients herself about Marianne's proximity and the proximity between the ventilation mask and the patient. Having noticed the locations of people and artefacts, she turns to the defibrillator to trigger the shock, as she has monitored the situation and decides that it is safe to shock.

This example showcases the importance of sequential time. Technically, Mie could have triggered the shock the moment the defibrillator was charged, without ensuring that Marianne had moved away with the ventilation mask. In the worst-case scenario, the shock would have affected and hurt Marianne, impacting her performance and increasing the risk of death to the patient. Cooperative work tasks, which take time, must be performed in a certain sequence by monitoring the clock time and coordinating based on the current progress. Sequential time is thus an important part of temporal orientation in the design of immersive the Cooperative Work Environment because it allows participants to order activities through sequences.

5 Discussion: Design Dimensions for creating immersive Cooperative Work Environments

CSCW research can offer unique contributions to Human–Building Interaction research (Alavi et al., 2019) by linking insights about professional cooperative work to the design of domain-specific buildings such as hospitals. However, a main challenge is to find methodological approaches that can help cooperative actors experience the building and inform architectural design in due time (Møller et al., 2016). We propose immersive Cooperative Work Environments as a methodological approach that uses VR and BIM technologies to inform the architectural design of hospitals. Moving from our specific empirical case of the hospital, we need to articulate the design dimensions critical for creating immersive Cooperative Work Environments. These design dimensions serve as ground for CSCW researchers to empirically design and implement immersive Cooperative Work Environments for any kind of domain-specific building.

5.1 The Cooperative design dimension for immersive Cooperative Work Environments

The cooperative design dimension which arrived from our work includes the *design of interdependence, articulation work, awareness, grounding, and sequential time*. Cooperative work is intrinsically social, as it is produced in situations where at least two people are mutually dependent in order to solve a shared task (Schmidt et al., 1992). The interdependency is thus a fundamental feature of cooperative work, and simply creating a VR representation of a building does not produce the experience of interdependency in work. A simple VR representation of the BIM model will fundamentally miss the contextual nature of the cooperative activities that are to take place in the building. The participants' cooperative engagements need to be immediately immersive in the situated (Suchman, 1987) and contextual environment if it is to function as a shared reference scheme for work (Clark et al., 1991).

In transforming the opportunity of the immersive Cooperative Work Environment into the understood reality of hospital work (Harrison et al., 1996), the geometric mathematical 3D models are not enough. Place emerges from *what healthcare professionals do* when producing healthcare work upon entering the immersive Cooperative Work Environment and beginning to conduct work (e.g., ALS). This is when the contextual nature of healthcare work transforms the 3D architectural models into a place where cooperative engagement can occur. We found that VR representation alone cannot be used to evaluate the architectural design of domain-specific building *without* the contextual nature of the healthcare practices. VR representations without cooperative work miss the activities that allow participants to *examine and evaluate* the architectural design. The very design of the immersive Cooperative Work Environment must require participants to become involved in the articulation work of coordinating, interrelating, and connecting individual yet dependent activities (Schmidt et al., 1992). Thus, while the CSCW design of technologies is concerned with *reducing* efforts of articulation work (*ibid*), the CSCW design of Human–Building Interaction informing architecture is about *preserving* the nature of articulation work as it exists in real-life work practices as a design strategy. It was evident that when healthcare practitioners in the immersive Cooperative Work Environment coordinated the ALS work, they were involved in articulation work. Articulation work is often accomplished through various types of awareness activities (Gutwin et al., 2002; Heath et al., 1992), where cooperative actors make their activities available through visual or auditory cues (Harper et al., 1989). We saw how the participants in the immersive Cooperative Work Environment used similar tactics such as talking out loud about their activities or glancing at each other to monitor each other's activities. Engaging with articulation work through strategies of awareness was only possible because of the virtual bodily presence mimicking the physical bodies of the participants. The sense of each other's activities became embedded in the immersive context, and was thus accomplished in and through the social organization of work critical for the intelligibility of the social interactions (Harrison et al., 1996; Heath et al., 1992; Heath et al., 1992).

CSCW research often focuses on the cooperative nature of work by unpacking the context of work, where the building is primarily in the background. Differently, when CSCW research engages in Human–Building Interaction, the focus is on *contextualizing the building*. Instead of considering the building and the layout as simply part of the context, CSCW research must attempt to bring context to the building. Contextualizing the building by adding cooperative features includes considerations for how participants can engage in grounding activities. Achieving grounding in digital environments is tricky and difficult (Bjørn et al., 2014; Bjørn et al., 2006; Olson et al., 2000), since such situations often miss a shared reference scheme. However, in the immersive Cooperative Work Environment, the visible bodily movement in combination with the contextual location of these movements provides a shared reference scheme supporting grounding. It is possible for participants to make an audible statement while pointing in a certain direction so that others can monitor and use these gestures as part of the sensemaking scheme interpreting the cooperative work. Designing for grounding in immersive Cooperative Work Environment is thus closely related to the design of awareness features in the process of preserving articulation work.

Finally, we found that temporal orientation is closely connected to the cooperative design dimensions in the form of sequential time. Some activities must come before others, and the correct sequence of sub-tasks is important. Prior CSCW research has unpacked the formal constructs in cooperative work and shown how the scripted nature of formal constructs can be used as a sequential coordination mechanism enabling articulation work (Schmidt, 1997). It was evident that when participants engaged in the immersive Cooperative Work Environment, they used their common knowledge of the scripted ALS workflow as a coordination mechanism orienting the temporal nature of the task. ALS is a scripted yet open-ended workflow. In CSCW research the general agreement is that simulating real-life cooperative situations in a 'laboratory' is problematic (Grudin, 1994), and the difficulty arises due to the problem of reliably capturing the complex but important social, motivational, economic, and political dynamics that take place in real life (Bjørn et al., 2014). However, in creating immersive Cooperative Work Environments, we are trying to find a way to bring cooperative work into the laboratory. Our immersive Cooperative Work Environment is based upon a prescribed medical interaction (ALS), which clearly provides a sequential order of activities while still leaving the interpretation work open, enabling a participant's situated actions. Because of the way we designed the cooperative work in the immersive Cooperative Work Environment, participants were able to adjust the task to the situatedness (Suchman, 1987), which allowed them an artificial, yet realistic, experience of their cooperative engagement (Schmidt et al., 1992). Balancing the situated actions and the prescribed workflow is essential, as the underlying sequential structure is required for orientation, and yet we must preserve the openness, interpretation, and situatedness in the immersive Cooperative Work Environment design.

5.2 The Professional work design dimension for immersive Cooperative Work Environments

The professional work design dimension derived from our work includes the *design of work practices, policies, artefacts, professional language, and clock time.* Contextualizing the building for a work domain requires in-depth empirical knowledge about how the professional work practices are to be carried out. In designing the work practices in the Cooperative Work Environment, we were careful to make it possible for participants to recognize and follow the policies – medical protocols – in the ways in which they engage with their shared task. However, CSCW recognizes the differences between plans and situated actions (Suchman, 1987); thus, our ethnographic insights about the real-life practices were crucial to ensuring an openness in the design, allowing participants to do what is needed when plans do not work out. For example, the *policy* of moving away from the patient and equipment when the shock of the defibrillator is being delivered was a medical protocol that was followed automatically; however, coordinating the task between participants was done in an open-ended manner.

Assessing the architecture of the domain-specific building includes evaluating the *artefacts'* locations and mobility (Bjørn et al., 2014) within the building. Domain-specific buildings are defined by having specific purposes to serve, which includes space for specific professional artefacts. Artefacts can take many different forms within hospital work (Bjørn et al., 2011; Svensson et al., 2007). However, in all cases, cooperative artefacts serve the important role of allowing healthcare professionals to do their work. While artefacts in hospital work are often considered to be interlinked and thereby impossible to consider as stand-alone entities (Bardram et al., 2005; Bjørn et al., 2014), we in our ALS workflow decided to focus only on artefacts as medical devices, such as the defibrillator and ventilation mask. This decision was based upon the fact that these were core medical devices embedded in the ALS workflow directing the professional healthcare work. Our empirical sessions clearly showed that having these artefacts was essential for the participants' experience and thus important for the design of the immersive Cooperative Work Environment. Further, we also witness how the participants use *professional language* to coordinate the ALS activities, and as such the immersive Cooperative Work Environment was able to produce a professional shared meaning context (Bjørn et al., 2009), where both professional language and artefacts guided the interaction and thus allowed participants to access the architecture.

Finally, temporal orientation also plays an important role for the professional work design dimension. We implemented fully functional professional artefacts based upon their physical counterparts, and two core artefacts were clocks (one over the door and one on the defibrillator). While we originally implemented these clocks in the immersive Cooperative Work Environment to mimic their real-life counterparts, the available information of *clock time* turned out to play a crucial role in the professional execution of the ALS workflow. Knowing and constantly paying attention to the time are part of the professional practice, and we saw how participants used both the clock on the wall and the digital clock on the defibrillator to keep time and to use the information for temporal orientation.

5.3 The Spatiotemporal design dimension for immersive Cooperative Work Environments

The spatiotemporal design dimension which arrived from our work includes the *design of loci, mobility, and action time*. Prior research classifies collaborative virtual environments as synthetic and remote, referring to how participants are 'transported' into an artificial immersive environment where they leave their bodies behind when arriving in a completely synthetic environment (Benford et al., 1996). While immersive Cooperative Work Environments obviously are synthetic creations made up by programming code transforming 3D BIM models into surfaces, weight, and gravity, the experience, while synthetic, is designed to be directly relatable to the real-world experiences of the architectural design. When participants are transported into our immersive Cooperative Work Environment, the link between their physical bodies is mimicked in the 3D world. Our participants did experience the immersive Cooperative Work Environment as 'real' and quickly accepted the fact that their experience of doing ALS was actually testing the architectural design of a future hospital. Thus, the close resemblance (by using the real-life BIM 3D models) allowed participants to link their experience to the real hospital, reducing the impact of the synthetic aesthetic which often is introduced with VR technology. Reducing the impact of the synthetic aesthetics of VR is an important design challenge for creating immersive Cooperative Work Environments, which fundamentally is about designing spatial properties such as loci (Harrison et al., 2008) and mobility (Bardram et al., 2005).

Locating people and artefacts in physical hospitals requires effort and articulation work in an attempt to preserve awareness of other people's activities and interaction with things. Further, such efforts include the work of ensuring that the right artefacts are available at the right time and place (Bossen, 2002). Without gravity and surface, the work involved in locating people (finding the patient suffering cardiac arrest) and in locating artefacts (finding the defibrillator down the hall) does not resemble real life. The immersive Cooperative Work Environment space cannot transform into a place without basic physics. The common orientation of humans in the physical world is based upon our common assumptions about what is up and down – right and left – as these directions are invaluable resources when interpreting activity and behaviour (Harrison and Dourish, 1996). Spatial orientation does not arrive automatically in immersive Cooperative Work Environments; instead, spatial orientation is produced through participants' interactions with people, artefacts, and the building. Thus, the building and architecture needs to "respond" to people's interactions as it would in the physical world. If pushing a bed becomes too easy (missing weight as a physical constraint), participants lose important information about spatial orientation. The digital architecture (wall and artefacts) must push back at participants to shape the spatial orientation, producing the semantic tangle of loci, activities, and people (Harrison et al., 2008). Said differently, the architecture must produce conditions to bound artefacts into locations, movements, and other artefacts shaping socio-material relations (Bjørn et al., 2014). By mimicking gravity and surface from the real world in the immersive Cooperative Work Environment, the design helps participants navigate, supporting them in producing place-based activities.

To produce the experience of mobility in immersive Cooperative Work Environments, temporal orientation matters. *Temporal orientation* related to mobility concerns the ways in which the design of the Cooperative Work Environment allows participants to explore moving through the immersive experience as a representation of what it means to move through the yet-to-be physical hospital. *Action time* is the time required to do a task, move between locations, or any other activity bound by time in the physical environment. Designing for action time in immersive Cooperative Work Environments requires designing movement in the immersive environment to resemble physical mobility in terms of time. Thus, for participants to explore the architectural design of the future hospital means that the time it takes to walk between rooms, departments, and wards in real life must to be measured and designed exactly into the immersive environment. For the immersive Cooperative Work Environment to be significant and in focus for the participants, the physical environment of participants bodies must be drawn into the remote environment (Benford et al., 1996). Virtual reality is transportation extreme, which means that the immediate environment becomes less significant (as in the physical bodily poses of nurses and doctors) because the attention is moved from the physical environment and is drawn in the remote environment. However, to link the movements to the contextual nature of the hospital, the movement of the physical bodies must have direct consequences in the immersive Cooperative Work Environment. Thus, the metaphor of remote/local as a dichotomy for Cooperative Work Environments does not fully align with the conceptual understanding of what it entails to participate in cooperative immersive environments. Instead, immersive Cooperative Work Environments are locally situated while remotely distinctive from the physical surroundings – making temporal features such as action time critical.

5.4 Design dimensions for immersive Cooperative Work Environments

We have now discussed the design dimensions for immersive Cooperative Work Environments divided into the cooperative, the professional work, and the spatiotemporal dimensions (see summarizing table 2).

Interestingly, the design of temporal orientation in the immersive Cooperative Work Environment emerged as an important feature in all three design dimensions. *Temporal orientation* requires that participants and their activities be visually accessible through digital means representing gestures and other bodily movements, which can be perceived and performed in the periphery of participants' focus (Heath et al., 1992). When people collaborate, they are engaged in interdependent yet distributed activities; thus, they do not need to know everything there is to know about others' work. Instead, they must be able to discriminate what in their local environment is important for them, and what is not. However, *spatial orientation* in the form of presence and awareness is not enough to assist participants in navigating the complexities involved in hospital work in the immersive Cooperative Work Environment. Temporal orientation in terms of action time, sequential time, and clock time is required. Mimicking spatial and temporal features is fundamental to designing immersive Cooperative Work Environments. Instead of using metaphoric approaches (Benford et al., 1996), the design work must create the context within which work can take place while focusing on the process of work itself. We used metaphoric design in a few places in the immersive Cooperative Work Environment (e.g. the oxygen mask). However, this design approach turned out to be problematic for interaction. The metaphoric approach required participants to learn about the interaction with the oxygen mask rather than simply use it. The context and the work itself are convoluted in immersive Cooperative Work Environments, since they melt together into one entity. Thus, in the design, we are trying not to detach context from the process of work but instead to create an immersive experience where participants can seamlessly interpret the two simultaneously.

We suggest temporal orientation as an important design recommendation when designing immersive Cooperative Work Environments. Temporal orientation is required for participants to gain temporal hints embedded in the VR scenarios to orient themselves towards their individual tasks, their cooperative task, artefacts, people, and their locations. The temporal orientation included three different types of temporal hints. Some relate to professional work, such as clock time; some relate to spatiotemporal characteristics, such as action time; and, finally, some relate to cooperative characteristics, such as sequential time. *Clock time* as temporal signalling and measurement; *Action time* as the required time it takes to do an action; and *sequential time* as the temporal ordering and coordination of sub-activities into larger shared tasks. We found that temporal orientation serves as an important structure for participants to navigate immersive Cooperative Work Environments, allowing them to assess the spatial layout and architecture of the domain-specific building.

Dimensions	Spatiotemporal	Cooperative	Professional
	Loci Mobility	Interdependence Articulation work Awareness Grounding	Work practices Policies Artefacts Professional language
Temporal orientation	Action time	Sequential time	Clock time

Table 2: Design dimensions for immersive Cooperative Work Environment

6 Conclusion

We offer immersive the Cooperative Work Environment as an approach to extend prior CSCW research by scaling the research focus from the design of technologies to the design of building. The immersive Cooperative Work Environment approach is not about creating technology to help healthcare professionals do their work; instead, the purpose is to create technologies that allow professionals to provide detailed and comprehensive feedback on buildings, which can inform architectural practice. We are thus not informing healthcare but informing architecture *about* healthcare. Balancing the two different yet interlinked cooperative work arrangement requires us to pay careful attention to *what* we are designing, and *who* we are designing for. We are designing both for healthcare work arrangements and for architectural work arrangement simultaneously. While it is the healthcare practitioners who are entering the VR simulation, it is the results of their experiences (e.g. the identification of the asymmetric door problem) that will impact architectural practices.

Our intention with this research was to identify which design dimensions are important when designing and implementing immersive Cooperative Work Environments with the purpose of simulating professional cooperative work informing architectural design practices. We identified three design dimensions: 1) the *cooperative dimension,* structured as the design of interdependence, articulation work, awareness, and grounding; 2) the *professional work dimension,* structured as the design of work practices, policies, artefacts, and professional language; and 3) the *spatiotemporal dimension,* structured as the design of loci and mobility. Finally, we also found that *temporal orientation* was a cross-spanning category relevant to all three design dimensions essential for participants' navigation within the domain-specific building.

Immersive Cooperative Work Environment are, at least so far, 'stand-alone' representations without direct access to other IT systems or data representations in the workplace we are trying to model. We left out important artefacts of healthcare practices, such as electronic medical records, digital hospital documentation procedures, and computers. In real-life ALS procedures, searching a patient's medical record during resurrection attempt is a critical task, e.g. to check allergies or to check whether the patient has asked not to be revived in case of heart failure. Evaluating Human–Building Interaction for architectural design should consider the building as a coherent entity, including considerations of all the technologies embedded (Alavi et al., 2019). A future research challenge is to extend our research to including the use of organizational IT systems as part of the 'simulations' that can take place in immersive Cooperative Work Environments. It would be an important research challenge to see whether Cooperative Work Environments can allow CSCW researchers to evaluate complex cooperative systems in laboratory environments, e.g. the use of digital triage systems in emergency departments (Bjørn et al., 2007), and thus bringing in complex work practices to the laboratory without losing the ethnographic richness required for such research.

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REFERENCES

Abraham, Joanna and Madhu C. Reddy (2013). Re-coordinating activities: an investigation of articulation work in patient transfers.In *Proceedings of the 2013 conference on Computer supported cooperative work*. San Antonio, Texas, USA: Association for Computing Machinery, pp. 67–78.

Alavi, Hamed; Elizabeth Churchill; David Kirk; Julian Nembrini and Denis Lalanne (2016). Deconstructing Human-Building Interaction. *Interactions*, vol. 23, no.6, pp. 60-62.

Alavi, Hamed S; Elizabeth F Churchill; Mikael Wiberg; Denis Lalanne; Peter Dalsgaard; Ava Fatah Gen Schieck and Yvonne Rogers (2019). Introduction to Human-Building Interaction (HBI): Interfacing HCI with Architecture and Urban Design. *ACM Transactions on Computer-Human Interaction*
vol. 26, no.2, pp. 6.

Andersen, Tariq; Pernille Bjørn; Finn Kensing and Jonas Moll (2011). Designing for collaborative interpretation in telemonitoring: Re-introducing patients as diagnostic agents. *International Journal of Medical Informatics*, vol. 80, no.8, pp. e112-e126.

Andersen, Tariq Osman; Jørgen Peter Bansler; Finn Kensing; Jonas Moll; Troels Mønsted; Karen Dam Nielsen; Olav Wendelboe Nielsen; Helen Høgh Petersen and Jesper Hastrup Svendsen (2019). Aligning Concerns in Telecare: Three Concepts to Guide the Design of Patient-Centred E-Health. *Computer Supported Cooperative Work (CSCW)*, vol. 28, no.6, pp. 1039-1072.

Balka, Ellen; Pernille Bjørn and Ina Wagner (2008). Steps Toward a Typology for Health Informatics. *2008 ACM Conference on Computer Supported Cooperative Work (CSCW), San Diego, CA, USA, 2008*. ACM. pp. 515-524.

Bannon, Liam and Susanne Bødker (1997). Constructing Common Information Spaces. Dordrecht: Springer Netherlands.

Bansler, Jørgen P; Erling C Havn; Kjeld Schmidt; Troels Mønsted; Helen Høgh Petersen and Jesper Hastrup Svendsen (2016). Cooperative epistemic work in medical practice: an analysis of physicians' clinical notes. *Computer Supported Cooperative Work*, vol. 25, no.6, pp. 503-546.

Bardram, Jakob (2000). Temporal Coordination - On Time and Coordination of CollaborativeActivities at a Surgical Department. *Computer Supported Cooperative Work (CSCW)*, vol. 9, no.2, pp. 157-187.

Bardram, Jakob and Claus Bossen (2005). Mobility Work: The Spatial Dimension of Collaboration at a Hospital. *Computer Supported Cooperative Work (CSCW): An International Journal*, vol. 14, pp. 131-160.

Bardram, Jakob and Claus Bossen (2005). A web of coordinative artefacts: Collaborative work in a hospital ward. *International ACM SIGGROUP Conference on Supporting Group Work (GROUP), Sanibel Island, Florida, USA, 2005*. Association for Computing Machinery. pp. 168-176.

Bardram, Jakob; Thomas Hansen and Mads Soegaard (2006). AwareMedia: A Shared Interactive Display Supporting Social, Temporal, and Spatial Awareness in Surgery. *CSCW'06 Conference on Computer Supported Cooperative Work, Banff, Alberta, Canada, 2006*. Association for Computing Machinery. pp. 109-118.

Bénard, Valérie; Myriam Lewkowicz and Manuel Zacklad (2006). Beyond Electronic Patient's File: Assisting Conversations in a Healthcare Network. *Frontiers in Artificial Intelligence Applications*
vol. 137, pp. 7.

Benford, Steve; John Bowers; Lennart E. Fahlén; Chris Greenhalgh and Dave Snowdon (1995). User embodiment in collaborative virtual environments.In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*. Denver, Colorado, USA: ACM Press/Addison-Wesley Publishing Co., pp. 242–249.

Benford, Steve; Chris Brown; Gail Reynard and Chris Greenhalgh (1996). Shared spaces: transportation, artificiality, and spatiality.In *Proceedings of the 1996 ACM conference on Computer supported cooperative work*. Boston, Massachusetts, USA: Association for Computing Machinery, pp. 77–86.

Benford, Steve; Mike Fraser; Gail Reynard; Boriana Koleva and Adam Drozd (2002). Staging and evaluating public performances as an approach to CVE research.In *Proceedings of the 4th international conference on Collaborative virtual environments*. Bonn, Germany: Association for Computing Machinery, pp. 80–87.
Benford, Steve; Chris Greenhalgh and David Lloyd (1997). Crowded Collaborative Virtual Environments.In *ACM SIGCHI Conference on Human Factors in Computing Systems*. Atlanta, Georgia, USA: ACM, pp. 59-66.
Benford, Steve; Chris Greenhalgh; Tom Rodden and James Pycock (2001). Collaborative virtual environments. *Commun. ACM*, vol. 44, no.7, pp. 79–85.
Bjørn, Pernille and Ellen Balka (2007). Health care categories have politics too: Unpacking the managerial agendas of electronic triage systems. Springer.
Bjørn, Pernille and Nina Boulus-Rødje (2018). Infrastructural Inaccessibility: Tech Entrepreneurs in Occupied Palestine. *ACM Trans. Comput.-Hum. Interact.*, vol. 25, no.5, pp. Article 26.
Bjørn, Pernille; Sue Burgoyne; Vicky Crompton; Teri MacDonald; Barbe Pickering and Sue Munro (2009). Boundary factors and contextual contingencies: Configuring electronic templates for health care professionals. *European Journal of Information Systems*, vol. 18, pp. 428–441.
Bjørn, Pernille; Morten Esbensen; Rasmus Eskild Jensen and Stina Matthiesen (2014). Does Distance Still Matter? Revisiting the CSCW Fundamentals on Distributed Collaboration. *ACM Trans. Comput.-Hum. Interact.*, vol. 21, no.5, pp. Article 27.
Bjørn, Pernille and Morten Hertzum (2006). Project-based collaborative learning: Negotiating leadership and commitment in virtual teams. D. v. Greunen and G. Marsden. *CHI-SA: Computer Human Interaction in South Africa, South Africa, 2006*. Association for Computing Machinery. pp. 6-15.
Bjørn, Pernille and Morten Hertzum (2011). Artefactual Multiplicity: A Study of Emergency-Department Whiteboards. *Computer Supported Cooperative Work (CSCW): An International Journal*, vol. 20, no.1-2, pp. 93-121.
Bjørn, Pernille and Ojelanki Ngwenyama (2009). Virtual team collaboration: building shared meaning, resolving breakdowns and creating translucence. *Information systems journal*, vol. 19, no.3, pp. 227-253.
Bjørn, Pernille and Kjetil Rødje (2008). Triage Drift: A Workplace Study in a Pediatric Emergency Department. *Computer Supported Cooperative Work (CSCW)*, vol. 17, no.4, pp. 395-419.
Bjørn, Pernille and Carsten Østerlund (2014). Sociomaterial-Design: Bounding Technologies in Practice. Springer.
Blomberg, Jeanette and Helena Karasti (2013). Reflections on 25 years of ethnography in CSCW. *Computer Supported Cooperative Work (CSCW): An International Journal*, vol. 22, no.4-6, pp. 373-423.
Boden, Alexander; Frank Rosswog; Gunnar Stevens and Volker Wulf (2014). Articulation spaces: Bridging the gap between formal and informal coordination.
Bossen, Claus (2002). The parameters of common information spaces: The heterogeneity of cooperative work at a hospital ward.In *Proceedings of the 2002 ACM conference on Computer supported cooperative work*. New Orleans, Louisiana, USA: Association for Computing Machinery, pp. 176–185.
Bratteteig, Tone; Ole Kristian Rolstad and Ina Wagner (2016). The Life and Death of Design Ideas. *Cham, 2016*. Springer International Publishing. pp. 259-275.
Brook, Benedict (2018). Billion dollar bungles at the Royal Adelaide Hospital, Australia's most expensive building, puts 'lives at risk'.
Bødker, Susanne and Erik Grönvall (2013). Calendars: Time Coordination and Overview in Families and Beyond. *London, 2013*. Springer London. pp. 63-81.
Ciolfi, Luigina; Geraldine Fitzpatrick and Liam Bannon (2008). Settings for Collaboration: the Role of Place. *Comput. Supported Coop. Work*, vol. 17, no.2–3, pp. 91–96.
Clark, Herbert H. and Susan E. Brennan (1991). Grounding in Communication. American Psychological Association.
Clarke, Karen; John Hughes; Mark Rouncefield and Terry Hemmings (2006). When a Bed is not a Bed: Calculation and Calculability in Complex Organisational Settings. Dordrecht: Springer Netherlands.
Crabtree, Andrew; Mark Rouncefield and Peter Tolmie (2012). Doing design ethnography. Springer.
Dourish, Paul (2006). Re-space-ing place: "place" and "space" ten years on.In *Proceedings of the 2006 20th anniversary conference on Computer supported cooperative work*. Banff, Alberta, Canada: Association for Computing Machinery, pp. 299–308.
Egger, Edeltraud and Ina Wagner (1992). Negotiating temporal orders: The case of collaborative time management in a surgery clinic. *Computer Supported Cooperative Work (CSCW)*, vol. 1, no.4, pp. 255-275.
Ellingsen, Gunnar and Eric Monteiro (2003). A Patchwork Planet Integration and Cooperation in Hospitals. *Computer Supported Cooperative Work (CSCW)*, vol. 12, no.1, pp. 71-95.
Fitzpatrick, Geraldine and Gunnar Ellingsen (2013). A Review of 25 Years of CSCW Research in Healthcare: Contributions, Challenges and Future Agendas. *Computer Supported Cooperative Work (CSCW)*, vol. 22, no.4, pp. 609-665.
Gergle, Darren; Robert E. Kraut and Susan R. Fussell (2004). Action as language in a shared visual space.In *Proceedings of the 2004 ACM conference on Computer supported cooperative work*. Chicago, Illinois, USA: Association for Computing Machinery, pp. 487–496.
Gerson, E (2008). Reach, bracket, and the limits of rationalized coordination: Some challenges for CSCW. Springer.
Gerson, Elihu M. and Susan Leigh Star (1986). Analyzing due process in the workplace. *ACM Trans. Inf. Syst.*, vol. 4, no.3, pp. 257–270.
Grinter, Rebecca E. (1996). Supporting articulation work using software configuration management systems. *Computer Supported Cooperative Work (CSCW)*, vol. 5, no.4, pp. 447-465.
Gross, Tom (2013). Supporting Effortless Coordination: 25 Years of Awareness Research. *Comput. Supported Coop. Work*, vol. 22, no.4–6, pp. 425–474.
Grudin, Jonathan (1994). Groupware and Social Dynamics: Eight Challenges for Developers. *Communications of the ACM*, vol. 37, no.1, pp. 92-105.
Gutwin, Carl and Saul Greenberg (2002). A descriptive framework of workspace awareness for real-time groupware. *Computer Supported Cooperative Work (CSCW): An International Journal*, vol. 11, pp. 411-446.
Harper, RR; John A Hughes and Dan Z Shapiro (1989). Working in harmony: An examination of computer technology in air traffic control. *Proceedings of the First European Conference on Computer-Supported Cooperative Work, 1989*. pp. 13-15.
Harrison, Steve and Paul Dourish (1996). Re-place-ing space: the roles of place and space in collaborative systems.In *Proceedings of the 1996 ACM conference on Computer supported cooperative work*. Boston, Massachusetts, USA: Association for Computing Machinery, pp. 67–76.
Harrison, Steve and Deborah Tatar (2008). Places: People, Events, Loci --- the Relation of Semantic Frames in the Construction of Place. *Comput. Supported Coop. Work*, vol. 17, no.2–3, pp. 135.
Hartson, Rex and Pardha S Pyla (2012). The UX Book: Process and guidelines for ensuring a quality user experience. Elsevier.
Heath, Christian and Jon Hindmarsh (2002). Analysing interaction. *Video Ethnography*, vol. pp.
Heath, Christian and Paul Luff (1992). Media space and communicative asymmetries: preliminary observations of video-mediated interaction. *Hum.-Comput. Interact.*, vol. 7, no.3, pp. 315–346.

Heath, Christian and Poul Luff (1992). Collaboration and Control: Crisis Management and Multimedia Technology in London Underground Line Control Rooms. *Computer Supported Cooperative Work (CSCW)*, vol. 1, no.1, pp. 69-94.

Heath, Christian; Marcus Sanchez Svensson; Jon Hindmarsh; Paul Luff and Dirk vom Lehn (2002). Configuring Awareness. *Comput. Supported Coop. Work*, vol. 11, no.3, pp. 317–347.

Hindmarsh, Jon; Mike Fraser; Christian Heath; Steve Benford and Chris Greenhalgh (2000). Object-focused interaction in collaborative virtual environments. *ACM Trans. Comput.-Hum. Interact.*, vol. 7, no.4, pp. 477–509.

LaViola Jr, Joseph J (2000). A discussion of cybersickness in virtual environments. *ACM SIGCHI Bulletin*, vol. 32, no.1, pp. 47-56.

Lee, Jiwon; Mingyu Kim and Jinmo Kim (2017). A study on immersion and VR sickness in walking interaction for immersive virtual reality applications. *Symmetry*, vol. 9, no.5, pp. 78.

Lidegaard, Martin (2011). Bekendtgørelse om anvendelse af informations- og kommunikationsteknologi (IKT) i offentligt byggeri.

Luff, Paul and Christian Heath (2012). Some 'technical challenges' of video analysis: social actions, objects, material realities and the problems of perspective. *Qualitative Research*, vol. 12, no.3, pp. 255-279.

Mentis, Helena M; Madhu Reddy and Mary Beth Rosson (2013). Concealment of emotion in an emergency room: Expanding design for emotion awareness. *Computer Supported Cooperative Work*, vol. 22, no.1, pp. 33-63.

Mentis, Helena M. (2017). Collocated Use of Imaging Systems in Coordinated Surgical Practice. *Proceedings of the ACM on Human-Computer Interaction*, vol. 1, no.78, pp. 1-17.

Møller, Naja Holten and Jørgen Bansler (2017). Building Information Modeling: The dream of perfect information. *15th European Conference on Computer-Supported Cooperative Work - Exploratory Papers, Sheffield, UK, 2017*. European Society for Socially Embedded Technologies (EUSSET). pp. 187-204.

Møller, Naja Holten and Pernille Bjørn (2011). Layers in Sorting Practices: Sorting out Patients with Potential Cancer. *Computer Supported Cooperative Work (CSCW)*, vol. 20, no.3, pp. 123-153.

Møller, Naja Holten and Pernille Bjørn (2016). In Due Time: Decision-Making in Architectural Design of Hospitals.In *12th International Conference on the Design of Cooperative Systems (COOP2016)*. Trento, Italy: Springer, pp. 191-206.

Møller, Naja Holten; Pernille Bjørn; Jonas Christoffer Villumsen; Tine Hancock; Toshimitsu Aritake and Shigeyuki Tani (2017). Data Tracking in Search of Workflows.In *2017 ACM Conference on Computer Supported Cooperative Work and Social Computing*. Portland, Oregon, USA: ACM, pp. 2153-2165.

Møller, Naja Holten and Signe Vikkelsø (2012). The clinical work of secretaries: Exploring the interaction of administrative and clinical work in the diagnosing process.In *10th International Conference on the Design of Cooperative Systems*. Marseille, France: Springer, pp. 33-47.

Møller, Naja L Holten (2013). Achieving Continuity of Care: A Study of the Challenges in a Danish and a US Hospital Department. *ECSCW 2013: Proceedings of the 13th European Conference on Computer Supported Cooperative Work, 21-25 September 2013, Paphos, Cyprus, 2013*. Springer. pp. 229-247.

Olson, Gary M. and Judith S. Olson (2000). Distance matters. *Hum.-Comput. Interact.*, vol. 15, no.2, pp. 139–178.

Orlikowski, Wanda J. and JoAnne Yates (2002). It's About Time: Temporal Structuring in Organizations. vol. 13, no.6, pp. 684-700.

Otto, Oliver; Dave Roberts and Robin Wolff (2006). A review on effective closely-coupled collaboration using immersive CVE's.In *Proceedings of the 2006 ACM international conference on Virtual reality continuum and its applications*. Hong Kong, China: Association for Computing Machinery, pp. 145–154.

Perkins, Gavin; Anthony Handley; Rudolph Koster; Maaret Castrén; Michael Smyth; Theresa Olasveengen; Koenraad Monsieurs; Violetta Raffay; Jan-Thorsten Gräsner; Volker Wenzel; Giuseppe Ristagno and Jasmeet Soar (2015). European Resuscitation Council Guidelines for Resuscitation 2015: Section 2. Adult basic life support and automated external defibrillation. vol. 95, pp. 81-99.

Randall, Dave; Richard Harper and Mark Rouncefield (2007). Fieldwork for design: Theory and practice. Cambridge, UK: Springer.

Reddy, Madhu and Paul Dourish (2002). A Finger on the Pulse: Temporal Rhythms and Information Seeking in Medical Work. *ACM Conference on Computer Supported Cooperative Work (CSCW), New Orleans, Louisiana, USA, 2002*. ACM. pp. 344-353.

Rodon, Joan and Alexander Chekanov (2014). Architectural constraints on the bootstrapping of a personal health record. *Scandinavian Journal of Information Systems*, vol. 26, no.2, pp. 53-78.

Sampaio, Alcinia Zita (2017). 4D/BIM model linked to VR technology.In *Virtual Reality International Conference - Laval Virtual 2017*. Laval, France: ACM, pp. 1-4.

Sarcevic, Alexsandra; Leysia Palen and Randall Burd (2011). Coordinating time-critical work with role-tagging.In *ACM 2011 Conference on Computer Supported Cooperative Work (CSCW)*. Hangzhou, China: ACM, pp. 465-474.

Schmidt, Kjeld (1997). Of maps and scripts: The status of formal constructs in cooperative work.In *International ACM SIGGROUP Conference on Supporting Group Work: The Integration Challenge*. Phoenix, Arizona, USA: ACM, pp. 138-147.

Schmidt, Kjeld and Liam Bannon (1992). Taking CSCW Seriously: Supporting Articulation Work. *Computer Supported Cooperative Work (CSCW)*, vol. 1, no.1-2, pp. 7-40.

Schmidt, Kjeld and Carla Simonee (1996). Coordination mechanisms: Towards a conceptual foundation of CSCW systems design. *Computer Supported Cooperative Work (CSCW)*, vol. 5, no.2, pp. 155-200.

Schmidt, Kjeld and Ina Wagner (2002). Coordinative artifacts in architectural practice. IOS Press.

Schmidt, Kjeld and Ina Wagner (2004). Ordering systems: Coordinative practices and artifacts in architectural design and planning. *Computer Supported Cooperative Work (CSCW)*, vol. 13, no.5-6, pp. 349-408.

Scupelli, Peter G.; Yan Xiao; Susan R. Fussell; Sara Kiesler and Mark D. Gross (2010). Supporting coordination in surgical suites: physical aspects of common information spaces.In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*. Atlanta, Georgia, USA: Association for Computing Machinery, pp. 1777–1786.

Soar, Jasmeet; Jerry Nolan; Bernd Böttiger; Gavin Perkins; Carsten Lott; Pierre Carli; Tommaso Pelli; Claudio Sandroni; Markus Skrifvars; Gary Smith; Kjetil Sunde and Charles Deakin (2015). European Resuscitation Council Guidelines for Resuscitation 2015: Section 3. Adult advanced life support. *Resuscitation*, vol. 95, pp. 100-147.

Souza, C. R. B. de and D. F. Redmiles (2011). The Awareness Network, To Whom Should I Display My Actions? And, Whose Actions Should I Monitor? *IEEE Transactions on Software Engineering*, vol. 37, no.3, pp. 325-340.

Strauss, Anselm (1988). The Articulation of Project Work: An Organizational Process. *The Sociological Quarterly*, vol. 29, no.2, pp. 163-178.

Strauss, Anselm; Shizuko Fagerhaugh; Barbara Suczek and Carolyn Wiener (1985). Social organization of medical work. Chicago, IL, US: University of Chicago Press.

Suchman, Lucy (1987). Plans and Situated Actions. The Problem of Human Machine Communication. Cambridge, UK: Cambridge University Press.

Svensson, Marcus Sanchez; Christian Heath and Paul Luff (2007). Instrumental action: The timely exchange of implements during surgical operation. L. Bannon, I. Wagner, C. Gutwin, R. Harper and K. Schmidt. *European Conference on Computer-supported cooperative work (ECSCW), Limerick, Ireland, 2007*. Springer. pp. 41-60.

Symon, Gillian; Karen Long and Judi Ellis (1996). The coordination of work activities: Cooperation and conflict in a hospital context. *Computer Supported Cooperative Work (CSCW)*, vol. 5, no.1, pp. 1-31.

Tanaka, Nobuhisa and Hideyuki Takagi (2004). Virtual reality environment design of managing both presence and virtual reality sickness. *Journal of physiological anthropology applied human science*
vol. 23, no.6, pp. 313-317.

Tang, Charlotte and Sheelagh Carpendale (2008). Evaluating the deployment of a mobile technology in a hospital ward.In *Computer Supported Cooperative Work*. San Diego, USA: ACM, pp. 205-214.

Tellioglu, Hilda and Ina Wagner (2001). Work Practices Surrounding PACS: The Politics of Space in Hospitals. *Computer Supported Cooperative Work (CSCW)*, vol. 10, no.2, pp. 163-188.

Wong, Hannah J.; Michael Caesar; Salim Bandali; James Agnew and Howard Abrams (2009). Electronic inpatient whiteboards: Improving multidisciplinary communication and coordination of care. *International Journal of Medical Informatics*, vol. 78, no.4, pp. 239-247.

Østerlund, Carsten S. (2008). Documents in Place: Demarcating Places for Collaboration in Healthcare Settings. *Comput. Supported Coop. Work*, vol. 17, no.2–3, pp. 195–225.