Seamless Integration of Multi-touch Table and Immersive VR for Collaborative Design

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—A Real-World Case of Designing Healthcare Environments

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Abstract

During the design of a new hospital, many different stakeholders are involved. These types of complex projects require more knowledge than any single individual possesses and in this context, it is necessary for all involved stakeholders to understand, participate, communicate, and collaborate with each other to obtain a high-quality outcome. This paper presents a collaborative design system, which support these creative and shared design processes. The presented system, Virtual Collaborative Design Environment (ViCoDE), features a seamless integration of a multi-touch table and several immersive VR-systems that support interactive and collaborative design work. The system has been evaluated during two studies in a real-world context of designing new healthcare environments (e.g. operating theaters). The results show that involved stakeholders better understand, participate, communicate, and collaborate with each other and that the multi-touch table and VR-system complement each other by facilitating different design spaces—both collaborative, as well as individual.

Keywords

Virtual reality • Collaborative design • CSCW

32.1 Introduction

When designing new healthcare environments and hospitals, many different stakeholders and specialists from healthcare and construction are involved with different experiences, knowledge levels and ability to interpret information. The most common information media in these processes are documents, descriptions, 2D-drawings and pictures. However, these media can be difficult to interpret and understand and place high cognitive demands on the viewer's ability to transform the information into a self-made mental image of the project. The self-made mental image could also be misinterpreted and differ depending on the individual's background, education, experience and interest. This means that important feedback from the

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healthcare specialists (e.g. surgeons, nurses) can be lost or disappear during the planning and design process. These malfunctions are detected later when it is too late and the healthcare environment is already built [1, 2].

One potential solution to this problem is to take advantage of immersive Virtual Reality (VR) instead of traditional 2D-drawings and pictures. While the use of this technology has been naturally limited in the past due to lack of available 3D data from the design process. The recent introduction of Building Information Models (BIM) within the AEC field has opened up new possibilities to us and extracted 3D data directly from the architect's own design environment [3, 4]. Because of this, use of real-time visualizations has become more accessible in practice [4, 5]. With the use of a Head-Mounted Display (HMD) the different stakeholders can move around and experience the future planned healthcare environment in scale 1:1 and therefore share a common frame of reference. However, with HMDs being primarily a tool for the individual, it makes it less suitable for active collaborative design work, which also relies much on face-to-face communication and gestures. In this context, it is also important to allow participants to express ideas and thoughts to the other members of the team by performing actual changes to the design.

In order to address the current situation this paper presents a new collaborative design system, which uses a seamlessly connected multi-touch table and several VR-systems for interactive and collaborative design. In addition to give technical details of the system, we present and discuss the results from using the system during two design workshops held as part of an ongoing design of two new hospitals.

32.1.1 Related Work

Computer-Supported Cooperative Work (CSCW) approaches are often based on the assumption that complex problems require more knowledge than any single individual possesses and in this context it is necessary for all involved stakeholders to participate, understand, communicate and collaborate with each other to obtain a higher quality outcome [6]. The resolution of the design problem grows out of the shared understanding that emerges as different stakeholders begin to better understand each other's perspectives [6, 7]. Still, communication breakdowns are often experienced because stakeholders have different interests and agendas and belong to different cultures that use different norms, symbols, and representations. However, by creating a shared understanding through collaborative design, it is possible to provide opportunities and resources for design activities embedded in a social creative design process in which all actors can actively contribute rather than having a passive consumer roles. In this context, interactive multi-touch tables have been shown to aid such a creative collaborative design process [6, 7]. The multi-touch table has the possibility to give the participant the feeling of an active and meaningful role during the meeting. Furthermore, [6] highlighted two different spaces in their collaborative design environment—action space and reflection space. Action space provides a foundation for creative collaboration between the participants and reflection space provides a foundation for the group members to validate and form their own opinions on the design.

However, a common problem with 2D-based design environments is that the information is not presented in such a way that people can understand it. In this context, real-time visualizations and Virtual Reality (VR) have been shown to offer an efficient communication platform [5, 8, 9]. With the ability to navigate freely through 3D scenes from a first-person perspective, it is possible to present and communicate ideas regarding future buildings in a way that facilitates understanding among all involved parties, despite their background or professional expertise. To further enhance user experience, it is commonly advocated to take advantage of immersive display technologies. Furthermore, [5] showed that immersive VR gave another level of understanding and perception of space, and that this is hard to experience in other type of visualizations.

The collaborative design system presented in this paper has been implemented with the intention of creating a system that supports a better creative and shared design processes for the involved stakeholders. To support this process, we have recognized that the system has to support better understanding, participation, communication, and collaboration between the different stakeholders. The hypothesis was that the multi-touch table and VR-system complement each other by facilitating different design spaces—both collaborative (i.e. action space), as well as individual (i.e. reflection space). In comparison to other systems [6, 7, 10, 11], our system supports interactive collaboration in both spaces, e.g. changes done in the multi-touch table or in VR are updated instantly in both spaces, as illustrated in Figs. 32.1 and 32.3.

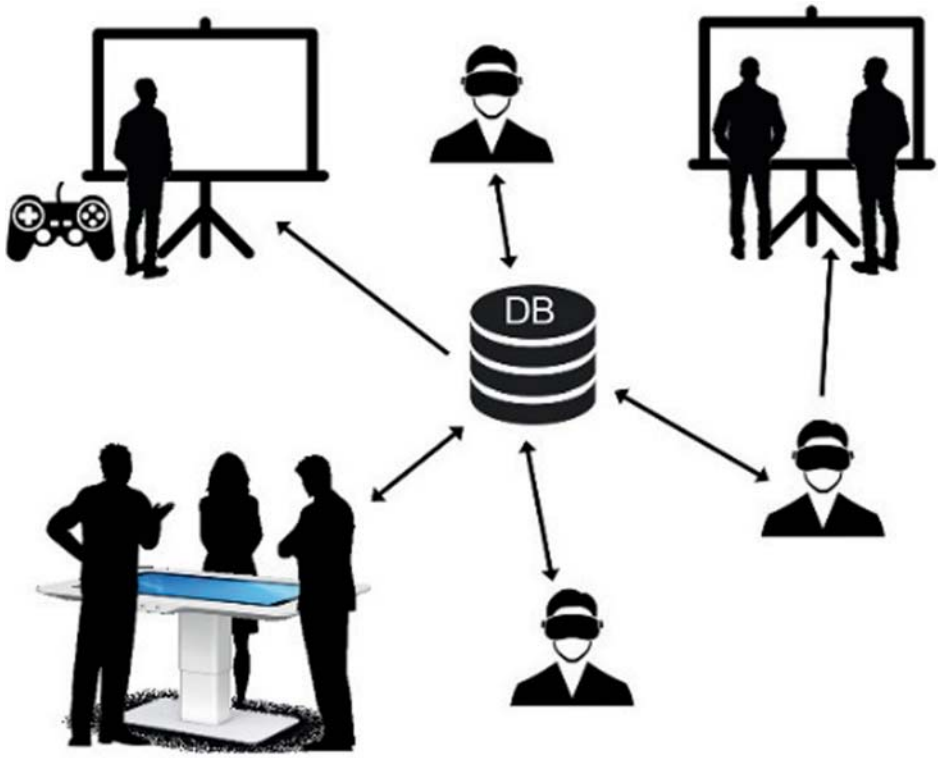

Fig. 32.1 The collaborative design system supports seamless integration of multiple viewer and interaction clients through a database/server

Fig. 32.2 Left: The multi-touch table used together with a non-immersive VR display, controlled by a wireless game controller (Picture from workshop 1). Right: The layout of the multi-touch table screen. Available components are accessible from a scrollable panel on the left side, and are added to the scene using drag-and-drop

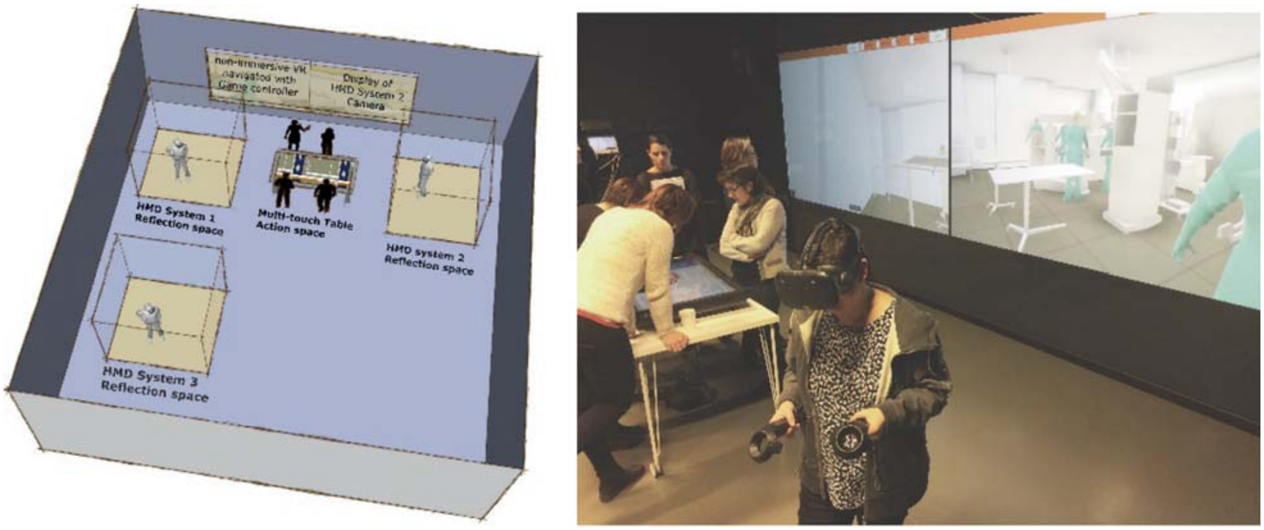

Fig. 32.3 During workshop 2, three HMD-system were seamlessly used together with the multi-touch table and non-immersive VR controlled by a game controller. This system supported both collaborative (e.g. action space), as well as individual (e.g. reflection space). The user of the HMD could interact within the VR environment by picking components and translated and rotated them using the HTC-Vive controllers

32.2 The System

The collaborative design system has been developed in the Unity Game Engine using C#. In essence, it consists of several viewer and interaction clients connected through a database/server, as illustrated in Fig. 32.1. The 3D-components in the database have unique IDs (GUID), which makes it possible to traces changes in the different connected client applications. Changes of a component's position or rotation in one client are uploaded to the server and then propagated to the other clients. However, as described below, not all clients support all degrees of interaction. The initial layout of the proposed design can be imported from the architect's design BIM-software (e.g. Autodesk Revit) and the components in the database are also BIM-objects.

32.2.1 Multi-touch Table and Big Screen Display

The layout of the multi-touch table is shown in Fig. 32.2. It represents the top view of the operating theatre and supports the typical multi-touch pan and zoom features used in most Smart-phones. To better illustrate the scale, a 1 × 1 m grid is applied on the floor as a texture. Furniture, medical equipment, walls and static avatars can be added, deleted, translated and rotated. All available components are accessible from a scrollable pane on the left side, and are added to the scene using drag-and-drop. Pressing and dragging a component will translate it whereas ticking it will show a circle for rotation and deleting. Furthermore, components that are mounted in the ceiling are given a different nuance in order to better emphasize their vertical position, see Fig. 32.2. The interface also supports simulation of how the ceiling pendant systems and its multi-movement arms can be moved around during surgery, making it possible to detect collisions with other equipment.

As seen in Figs. 32.2 and 32.3, the contents of the scene can also be displayed on a big screen from a perspective controlled by a wireless game controller, i.e. non-immersive VR.

32.2.2 VR-System

The HTC-Vive was used as the immersive display system and a teleportation locomotion mode was used for navigation [12]. Within the VR environment, components can be translated and rotated. A component will be highlighted if it intersects with any of the HTC-vive controllers and pressing/releasing the trigger allows a user to pick it up and re-place it within the scene.

To help the user with the positioning, a component is always restored to its up-right position at the correct elevation above the floor upon release (i.e. to avoid tilting). As illustrated in Figs. 32.1, 32.2 and 32.3, it is also possible to display a user´s view from VR on a big screen display.

32.3 The Study

The results in this paper are grounded on two workshops conducted in the spring of 2016 and 2017, respectively. During these workshops the collaborative design system was used in the context of designing operating theatres. The participants were different stakeholders and specialists from healthcare and construction, e.g. theatre nurses, anesthesiologists, architects and project managers, for the intended operating theatres in Skaraborg and Östra Hospital, both located in Västra Götaland, Sweden. All of the participants had previous experience of dialogue-based workshops using traditional information media, such as 2D-drawings and pictures.

The main difference between the two workshops from a technical point of view was that the first one required an export of the scene to another application to be able to view it in HMD. Also, only one HMD was available and it was not possible to move any of the components in the VR environment. The second workshop, however, used the final system as described in the previous section.

The first workshop had 8 participants and lasted for six hours. It consisted of two different design tasks; the first one being to design an operating theatre in a pre-defined space (approx. 8 × 9 meters), and the second one to design an operating theatre without any constraints on room size. The time used for each of the design tasks was equal.

The second workshop had 9 participants and lasted for four hours. It consisted of two different design tasks; the first one being to design an operating theatre in a standard sized room (approx. 8 × 9 meters), and the second one to design an operating theatre in a room of extended size (approx. 10 × 9 meters) followed by a step to shrink the extents of the room (i.e. by moving the walls closer to the equipment). The layout of the proposed operating theatre design came from the architect's BIM from the project. The time used for each of the design tasks was equal. Figure 32.3 shows the room layout and the different collaboration and visualization systems used during the second workshop.

On both occasions, the workshop started with a 10 min introduction of the system in order for the participants to familiarize themselves with the user-interfaces and the overall functionality.

32.3.1 Method

During both workshops, data was extracted by means of documented observations as well as unstructured interviews with the participants about their thoughts and experiences in relation to the collaborative design system. On both occasions three researchers were present. The workshops were facilitated mainly by the architect, with technical support from the researchers. The second workshop was also recorded with two stationary video cameras and the recorded material was transcribed and later compared to the field notes in order to reinforce the observations made. Being that the cameras were placed in elevated positions the recorded material also provided a better overview of the participants´ movement around and between the different stations in the workshop room.

32.4 Result and Discussion

The result from the two workshops showed that the participants found that the three different visualization and interaction techniques complemented each other effectively. The multi-touch table gave support for interactivity and supported creativity and collaboration to solve the task together. The 3D-view from the projector, (i.e. none-immersive VR), gave a better picture and understanding of the operating theaters. The HMD gave a further dimension to better understand the space and the size of the room. By using the HMD the different participants could actually stand at the operating table in the virtual operating theater and make sure everything felt correct.

32.4.1 Support Better Understanding and Communication

The participants at the workshops expressed that this collaborative design system gave them better understanding and communication. The observation and the video analyses from the workshops recognized that the multi-touch table created a shared understanding and that resolution and solution of the design problem emerged as different participants/stakeholders began to understand each other's perspectives. The project manager and architect had the layout and total size of the room (i.e. connected to construction cost) on their agenda, while healthcare staff focused on functionality and task-related aspect of performing surgery.

However, during the workshops it was recognized that the "2D-topview" on the multi-touch table was not enough, as it was difficult to interpret and understand. As the design progressed, the participants started to observe several design errors and clashes between equipment in the 3D-view from the projector. Although the ceiling-mounted equipment had a different nuance to indicate it´s vertical placement, it was still difficult to perceive it correctly from the top-view in the multi-touch table. In particular, it was difficult to understand how much vertical space the equipment required. After the participants' had identified this, they started working with both the multi-touch table and the 3D-view from the projector as a reference. They started to test how the ceiling pendant systems and its multi-movement arms moved around during surgery so that it would not collide with anything. During the second workshop, the participants also had the opportunity to do this validation in the HMD, which gave them an even better understanding of how the operating theater would actually function.

Furthermore, during both workshops the participants used the HMD, to do design reviews and validate and examine the operating theaters. They had the opportunity to virtually stand by the operating table and make sure that they could see and reach all the equipment and make sure everything was correct. In this setting it was also possible to make changes to design. All the participants mentioned that HMD display gave a superior level of understanding and perception of space and that you could do more detail changes in the design as it was in scale 1:1.

32.4.2 Support Better Creativity, Collaboration and Participation

The participants at the workshop expressed that the collaborative design system was user-friendly, fun to use and that the system encouraged them to solve the design task effectively. Observation from the two workshops showed that the participants became easily familiar with the user interface and started to use the system directly after the introduction. Furthermore, the participants mentioned and thought that the workshop was a socially creative design process in which all participants could actively contribute with both their knowledge and experience. The observation during the workshops was that the workshop became a very creative design process, were the different participants shared knowledge and experience. The architect highlighted that she thought the roles were changing, i.e. the architect became an administrator of the workshop and healthcare staff became designers/architects and thereby more active and involved in the process. According to the architect and project manager, this had not been the case during earlier traditional dialogue-based workshops. The architect also stated that the knowledge and experience transfer from the healthcare staff was better with the collaborative design system. Furthermore, the participants from the healthcare staff perceived that the tools gave a better understanding of the design and planning of physical spaces and that their professional skills were presented and extracted in a better way. During the first workshop, the healthcare professionals from the different hospitals exchanged knowledge and experience from their healthcare environments. Also, in this dialogue, the participants mentioned that some professions were missing during the workshop, such as facility management, operations, logistics etc., which they believed would also have benefited from using the system.

The architect and project managers argued that this collaborative design system and it´s dialogue-based workshop offered a more efficient process compared to the traditional one. The architect explained that in the traditional process, it often entails long cycles (e.g. weeks) between new proposals and feedback from the end-users. Instead, they experienced that this new type of collaborative design process provided almost immediate feedback.

32.4.3 Support for Different Design Spaces

As mentioned, the different visualization and interaction techniques gave different support to the users during the workshop, effectively supporting different design spaces. Primarily, the multi-touch table supported a social creative process between the participants, i.e. action or collaboration space, see Fig. 32.4.

Fig. 32.4 The multi-touch table supported a social creative process (Picture from workshop 1)

The setting around the multi-touch table was highlighted as the most natural in terms of inter-communication as it supports face-to-face communication and gestures. However, the observations during the workshops also showed that the participants' ability to transform the multi-touch table information into self-made mental images in 3D was demanding, difficult and gave misinterpreted understandings. This was observed and noticed during both workshops when the users started using the 3D-view from the projector and detected design errors of colliding equipment between the ceiling-mounted equipment. After recognizing the design errors and the misinterpreted understandings, the users started to include the 3D-view from the projector as a shared frame of reference in their collaboration. They used the multi-touch table interface for designing and used the 3D-view from the projector as a visualization medium for understanding 3D-space better and for validation of the design. During the workshops it also became clear that immersive VR (e.g. HMD) gave another level of understanding and perception of space, which is hard to experience in other type of visualizations. The users performed design reviews and validations by actually standing virtually next to the operating table in order to make sure that everything was correct. The immersive VR system facilitated a reflection space where the user had the opportunity to considerate, reflect, validate and confirm the design related to their future work environment and task performed in the operating theater. What was observed during the first workshop when the user used the immersive VR-system, was that they wanted to do detailed changes of the design and they communicated the proposed changes to the other participants while they were in the immersive environment. As a result of this, the second workshop had seamless integration of a multi-touch table and several immersive VR-systems that supported interactive and collaborative design work in different design spaces—both collaborative (e.g. action space), as well as individual (e.g. reflection space). Changes done in one of the spaces were updated in the other design spaces. In the second workshop featured three HMD systems and one of them shared the 3D-view on a projector, (see Fig. 32.3).

32.5 Conclusions

Revisiting the foundations for successful collaborative design work, we can identify several aspects that a systems solution needs to support:

- Create awareness of each other's work and provide mechanisms to help draw out the tacit knowledge and perspectives.
- Enable co-creation (in multiple forms: simultaneous, parallel, and serial).
- Allow participants to build on the work of others.
- Provide individual reflection and exploration.

As the results show from our study, our system provides all of these features. Multi-touch table combined with non-immersive VR, supports interactive collaboration with shared understanding and awareness, and provides mechanisms for creative collaboration and tacit knowledge transfers. By providing seamless integration, usage and collaboration between different systems it also facilitates collaboration in simultaneous, parallel, and serial. The participants could also build on the work of others, which was the case during the workshops. As the results showed, the multi-touch table and VR-system complement each other by facilitating different design spaces—both collaborative (i.e. action space), as well as individual (i.e. reflection space). In comparison to other systems, our system seamlessly supports interactive collaboration in both spaces, i.e. changes done in both multi-touch table, non- and immersive VR-systems are updated seamlessly in both spaces. However, what was noticed during the workshops was that participants primarily wanted to engage in the collaborative design around the multi-touch table and did not take the time to reflect and do design review in the HMD. Furthermore, what happened when they took the time to reflect and perform the design review in VR, they found and had a lot of input to the others. Therefore, in future workshops it is important to facilitate the collaborative design process, by a break and giving the participants time for design review and reflection in the immersive VR environment. During these design review and reflection sessions, the participants stated that the HMD gave them another level of understanding and perception of space and the design problem that they could not experience in the other mediums. Our study thus reinforces the theory that multiple design spaces are, indeed, needed in order to foster a collaborative and creative design environment.

For future work it would be interesting to evaluate some of the suggestions given by the participants, such as collision detection among components and color-coding the different equipment according to professional discipline to better illustrate different responsibilities. Furthermore, seamless integration of BIM-systems would be a natural extension of the system, e.g. trace changes and update the BIM automatically. This would then also make the system support other project types, e.g. schools, urban environments, construction sites.

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