An Asymmetric Collaborative System for Architectural-scale Space Design

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ABSTRACT

We present a system that facilitates asymmetric collaboration among users with two different viewpoints in the design of living or working spaces. One viewpoint is that of the space designers, who observe and alter the space from a top-down view using a large tabletop interface. The other viewpoint is that of a space occupant, who observes the space through internal views using a head-mounted display. We conducted two studies to understand how our system support users in architectural-scale space design. One is about preliminary user study to observe general behavior to Dollhouse VR system, and the other one is a case study that users are actual employees of restaurant and discuss rearrangement of floor by moving tables and chairs in virtual environment. Results showed that the system supports a pair of interaction techniques that could facilitate communication between these two user viewpoints.

CCS CONCEPTS

• **Human-centered computing** → Computer supported cooperative work;

KEYWORDS

Virtual reality, table top, CSCW

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1 INTRODUCTION

Architecture-scale space design is affected by various kinds of constraints and thus involves a wide variety of experts in such areas as architecture, electrical, interior/exterior design, air conditioning, safety, legal, and marketing. It is usually difficult for a single person designing a space to consider all the constraints. For example, someone planning to build a house for his or her family may want a large glass cabinet for displaying favorite things, but it may not satisfy safety requirements. Or the owner of a restaurant working on the table arrangement may want as many tables as possible to maximize the number of customers, but the layout may not leave enough space for serving staff.

To address this problem, we propose using a virtual reality system that provides a collaborative design workspace for architectural-scale space design. This "Dollhouse VR" system supports two viewpoints; a top-down view for observing a 3D model from outside and a first-person view for creating the experience of being in the space. This system uses a doll avatar to represent an occupant in

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Figure 1: Dollhouse VR interfaces: a top-down external view for designers (top left); immersive internal view for space occupant (bottom left).

the virtual reality (VR) space and provides two interaction techniques for multi-person, multi-view collaboration and discussion. One creates a see-through ceiling in the virtual space that provides a feeling of being in the 3D model. The other marks a point of interest, i.e. a location to which a designer or the occupant points in the virtual space. In this paper, we describe the details of the system and present two user studies that clarified the benefits and limitations of the system.

The main contributions of this work are as follows.

- We created a working prototype system that realize an asymmetric collaborative workspace for architecture-scale design.
- We proposed an interaction design for the asymmetric collaborative design; a giant finger and see-through ceiling.
- We conducted a preliminary user study and a case study to understand how our system support users in architecture-scale space design.

2 RELATED WORK

2.1 Virtual Reality and Augmented Reality

The emergence of HMDs has enabled users to become immersed in a virtual space. An HMD user can easily experience the virtual world from viewpoints that cannot be experienced in their daily lives [Rheiner 2014]. A similar idea has been applied to the real world. Nishida et al. displayed a child's eye view on an HMD by placing a camera on the user's waist to capture the view [Nishida et al. 2015]. We developed a system that seamlessly integrates views of a virtual and the real world. There have been many attempts to augment the real world with virtual objects, resulting in technologies like augmented reality [Feiner et al. 1993; Milgram et al. 1995]. In contrast, there are few examples of augmenting a virtual world with objects from the real world. Our proposed system integrates a real world view into a virtual world by using a see-through ceiling technique.

2.2 Top-down Perspective on Tabletop Display

Traditional computer-aided design systems enable a user to view and manipulate a virtual space on a tabletop. However, since such systems are made for use by a single expert designer, it is difficult for multiple users to collaboratively work on it. There have been many attempts to facilitate such collaborative work. The Urp system for urban planning simulates building shadows in real time by using miniature architectural models [Underkoffler and Ishii 1999]. Horiuchi et al. presented a collaborative workspace for theatre production comprising a miniature theatre and tangible dolls [Horiuchi et al. 2012]. Kim and Nam developed a toolkit for making architectural prototypes [Kim and Nam 2015]. Although many strategies like those used in these examples facilitate collaboration, all the participants in the collaborative workspace have only a top-down view. Our system enables a person with a first-person view to participate in the discussion.

2.3 Asymmetric Viewpoints for Design

Several previous research efforts have proposed using interfaces with multiple asymmetric viewpoints. The I-m-Cave interface simulates taking a tour through a cave [Huang et al. 2014]. A top-down view of the cave map and a first-person view in the cave are given at the same time through tabletop and tangible doll interfaces. "Tangible earth" is a tangible learning environment with multiple viewpoints. It gives a global view and a local view through a doll-like figure and a globe [Kuzuoka et al. 2014]. There are also several design environments with multiple asymmetric viewpoints. The WIM (Interactive Worlds in Miniature) interface displays two images of a VR space simultaneously on an HMD: one shows a miniature version of the space, and the other shows a full-size version [Stoakley et al. 1995]. Anderson et al. proposed using a desktop design environment with VR in which multiple viewpoints are displayed on an HMD [Anderson et al. 2003].

All of these systems were designed for a single user without consideration of collaboration. Example systems that provide a collaborative workspace with multiple asymmetric viewpoints are those proposed by Bonanni et al. [Bonanni et al. 2009] and Hosokawa et al. [Hosokawa et al. 2008]. They enable multiple users to manipulate a space through tangible objects with a first-person view shown on the display. However, these systems require the users to switch their viewpoints repeatedly. Holm et al.proposed a collaborative VR environment for designing products from different viewpoints [Holm et al. 2002]. Also Leigh et al. proposed a collaborative VR environment [Leigh et al. 1996]. Chenechal et al. presented a system that employs an immersive and a global view for spatial planning [Chenechal et al. 2015]. IEEE 3DUI conference held a contest in 2012 focused on creating an asymmetric collaboration navigation interface and displays [IEE 2012].

However, the communication function does not facilitate natural communication among the users. In contrast, with our proposed Dollhouse VR system, multiple users, inside and outside the virtual environment, can discuss the design while concentrating on their asymmetric viewpoints by using two interaction techniques that facilitate natural communication. Ibayashi et al. demonstrated a collaborative VR system at a conference exhibition, and its one-page abstract was a non-archival and only presented system design briefly [Ibayashi et al. 2015]. This paper describes the details of the system and presents a preliminary user study and a case study that clarified the benefits and limitations of the system.

3 DOLLHOUSE VR

Our proposed system is designed to facilitate communication and discussion among people outside the virtual environment (i.e. in the real world) and a person inside the virtual environment (e.g. wearing an HMD).

3.1 External and Internal Views

The external, or top-down, view is provided on a large tabletop interface. It enables designers to manipulate the space so as to change its layout in the 3D virtual environment (Figure 1, top left). All interactions involve touch (dragging or tapping on the interface). Multiple designers can use this interface simultaneously. They can manipulate and rotate virtual objects by dragging. Gestures implemented include 1) single finger dragging which translates object 2) double fingers rotating which rotates object. They can also duplicate them by triple-tapping.

The internal view is a first-person view of the virtual environment (Figure 1, lower left). The occupant sees and walks around the environment using an HMD and a joystick and switches the viewpoint between standing and sitting by pressing a button on the joystick. To enable both designers and the occupant to have a sense of sharing the same space, we place a doll avatar in the space that mirrors the occupant’s movements (e.g. walking and head turning). The system represents the direction of the occupant’s view by using an arrow.

3.2 Interaction Techniques to Facilitate Communication

To enable collaborative discussion, it is critical to achieve effective and efficient communication between the users inside and outside the virtual environment. However, communicating with a user in a virtual environment is particularly difficult because an HMD covers the user’s face, especially the eyes, hindering natural face-to-face communication. To address this problem, we introduce two interaction techniques. Our goal is to provide natural awareness of the behaviors of the other users in the design environment.

3.2.1 See-through Celling: We made the ceiling of the virtual space transparent and use it as a communication channel between the designers and the occupant. From the designers’ perspective, they can see the occupant moving around in the space by looking down through the open ceiling. The head orientation of the occupant is tracked by the HMD and is mirrored by the head orientation of the avatar (the doll). From the head orientation, the designers can see the occupant’s behaviors and infer his or her intentions.

From the internal view, the occupant can see the designers’ faces by looking up through the ceiling. The designers’ faces are captured by a camera mounted on the tabletop device, and the captured view is mapped to the ceiling (Figure 1, lower left). The camera has a fisheye lens that captures the entire face and upper body of the designers. If the occupant wants to know how the designers’ discussion is going, he or she can look up and see the designers’ faces through the ceiling. To give a better awareness of the designers to the occupant, the system darkens the floor a little bit to represent the shadows of the designers. This provides natural awareness of the designers’ locations and thus facilitates natural and efficient communication.

3.2.2 Pointing to Target of Interest: The see-through ceiling enables all the users to see the behaviors and infer the intentions of the other users. However, the ability to see the finger orientations of the other users enables their intentions to be inferred more precisely. Therefore, we provide additional functions so that each user can use a finger to clarify what he or she is talking about.

To enable the occupant to see what a designer is talking about, the system uses the touch-sensitive tabletop device to detect the designer’s finger position and shows one finger coming down from the ceiling into the occupant’s immersive view (Figure 2), as in a “god-like” interaction technique [Stafford et al. 2006]. It shows a 3D hand model instead of the user’s actual hand, as done elsewhere [Stafford et al. 2006]. This enables the occupant to easily recognize what the designer is pointing at or manipulating. about.

On the occupant’s side, the pointing function is implemented with the joystick (Figure 3). If the occupant wants to point at an object in the virtual environment, he or she uses the joystick to control the direction of the avatar’s arm and to create a pointing finger if desired. The designers then see the occupant’s arm/finger orientation via the posture of the avatar.

3.3 Prototype Implementation

Our current prototype implementation is mainly designed for furniture layout. We created the Dollhouse VR system by using the Unity 5 development platform on a laptop computer (Windows 8.1). In this system, two different applications are executed on different PCs and are connected via a wireless network (Wi-Fi). One application displays the external view on a large interactive tabletop display,

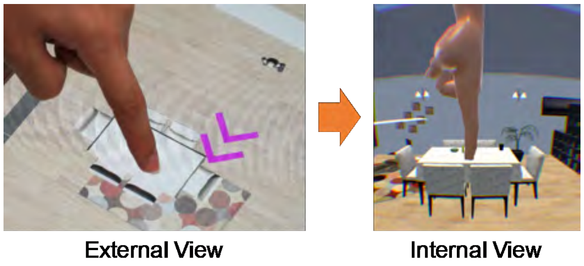

Figure 2: Once a designer touches on the external view, a giant finger is coming down from ceiling in the immersive view.

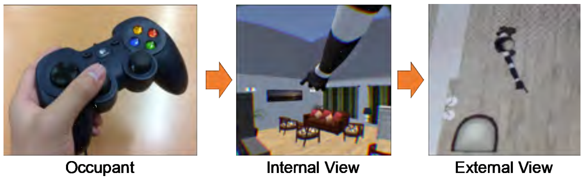

Figure 3: An occupant points to objects by manipulating joystick.

which is connected to a laptop computer (ASUS-NotebookSKU). The other application is executed on another laptop computer (G-tune i5702) with an HMD (Oculus Rift DK2, resolution of 960×1080 per eye, frame rate of 75 fps) and a joystick (Elecom Wireless Gamepad) connected. Flatfrog Multitouch 3200 32" Full-HD touch display was used during preliminary user study while Iiyama PL2735M 27" Full-HD display was used during case studies for its portability. Maximum 10 fingers can be used to control our interface.

4 PRELIMINARY USER STUDY

We conducted a preliminary user study in a hypothetical room layout task to explore how users utilize the system, especially how an occupant in the environment and designers outside the environment communicate. In this study, we collected 3D furniture models from the Unity asset store and placed them in a virtual house model.

4.1 Method

Three volunteers participated in this study (Figure 4, left). They were undergrad or graduate students at a local university. One had prior experience with virtual environments (i.e. wearing an HMD). The participants took turns playing the roles of occupant and designer. The task was to design a room using the furniture we had placed in the virtual house model. Specifically, they were told to arrange the furniture in any way they liked through free discussion with each other. This task, including a final interview, took about one hour.

4.2 Results

All the participants immediately understood how the Dollhouse VR system could be used to complete the task and used the communication function as intended. Once the function of the see-through ceiling was explained, all of them immediately understood the relationship between the designers and the occupant. This indicates that the structure of our system is intuitive. For example, one participant in the role of the occupant said, "[It is] on my right," and a designer then naturally shifted his or her gaze to the indicated position. Likewise, when a participant in the role of the occupant used the joystick to point to a location of interest, the designers shifted their gaze to that location. These interactions were done without the occupant removing the HMD.

The interactions on the designers' side were similar to conventional ones using 2D drawings. There was no evidence of difficulty in manipulating the space. However, the capabilities of our system were not always used. For example, although the "giant finger" technique worked well for showing the occupant where a designer was pointing (Figure 4, right), the designers sometimes pointed without touching the display, and a giant finger is created only when a designer is touching the display.

5 CASE STUDY: REARRANGE FLOOR LAYOUT FOR RESTAURANT

In the second case study, we explored how professionals communicate with each other using the Dollhouse VR system. The task was to rearrange the floor layout of a banquet room in an actual restaurant.

Figure 4: Scene from preliminary study (left), and occupant's immersive internal view. Giant finger is coming from ceiling (right).

5.1 Method

The four volunteer participants (Figure 5) were employees of a national chain restaurant in Ganko Food Service Co. ltd. with different expertise: management and serving, sales and marketing, architecture, and executive. They had previously worked together on the design of the restaurant. In this case study, they used our system to examine alternative table layouts for a banquet room. The task was important because maximizing its capacity by arranging the furniture directly affects their income.

A virtual 3D model of the banquet room with fixtures, plus dining tables with 4 or 6 chairs each, a hanger rack, and a service stand, was created using CAD software (Figure 6). There were 8 tables and 48 chairs in the initial layout representing the current layout of the room. The scale and size and floor layout were adjusted to visually match those of the actual environment. Virtual customers sitting in a wheelchair were also placed in the environment to investigate accessibility. After setting up the system, which took about 30 minutes, we gave the participants instructions for using it (10 min). They then used the system to design the floor plan (1 hour). Finally, we conducted an informal interview to collect feedback about the system (20 min). The total time taken by the participants was about one and a half hour.

Figure 5: Scenes from second case study.

5.2 Results

The participants started by adding tables to the initial layout. They achieved a capacity of 56 seats without altering the initial layout (Figure 7 (a)). However, they noticed that the walkway was too narrow for the food servers to pass through. With this concern in mind, they altered the layout further and achieved a capacity of 58 seats (Figures 7 (b–c)). The person with sales and marketing expertise then proposed adding an extra row of tables, forming a

Figure 6: Environment and components normally used in restaurant.

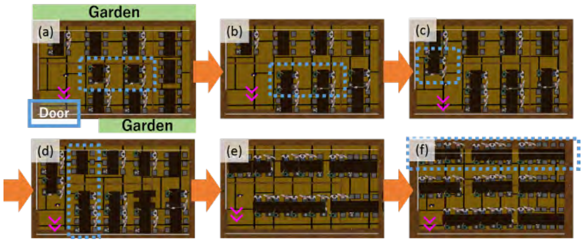

Figure 7: Transition of restaurant layout.

Figure 8: Occupant gesturing to indicate width of walkway (left). Designer manipulating dining set following feedback from occupant (right).

4×5 array of tables and pushing the capacity to 74 seats. However, the participant wearing the HMD noticed that this plan was unachievable because the space around the entrance was too narrow (Figure 7 (d)).

Next, one participant proposed rotating the tables 90°, resulting in a maximum capacity of 60 seats (Figure 7 (e)). The participant with sales and marketing expertise said, "This kind of table layout has never been considered before." Another participant added an extra row to the layout, producing a maximum capacity of 92 seats (Figure 7 (f)). However, after experiencing the result in Dollhouse VR, the participants agreed that the layout was impractical because a wall would have to be moved.

5.3 Findings of Specific Interaction, Communication, and Comments from Participants

Dollhouse VR facilitated an in-depth business discussion. The participants, being familiar with the restaurant and its daily operation, discussed not only the layout of the banquet room but also operational issues related to both the servers and the customers. They also calculated how much they should extend the environment to hold the expected number of dining sets which is shown in Figure 7 (f) by using a virtual ruler. Moreover, they discussed plans for building a new restaurant. They had an in-depth discussion of the optimal capacity considering the population of the area and number of large employers, which was very fruitful for future business development.

The participants demonstrated several interaction and communication patterns unique to Dollhouse VR. First, a participant playing the role of occupant indicated to the designers the width of the walkway in the 3D space by gesturing (Figure 8 left). We also frequently observed that a designer manipulated the dining set following feedback from the occupant (Figure 8 right). This real-time collaboration demonstrated the benefits of Dollhouse VR.

The participants made several suggestions for improving the system. The person with executive expertise said, "Dollhouse VR should calculate the cost to achieve each layout." The person with design expertise suggested that interactive models be used to enable visualization of customer behavior patterns. We observed that the occupant frequently took off the HMD in order to see the layout from the designer's view. The person with management expertise said, "I would like to use the system for staff training," which is an unexpected usage of Dollhouse VR.

6 DISCUSSION

In our study, we observed active collaborative interaction between the designers and occupant. They communicated with each other using the "See-through Ceiling" and "Pointing to Target of Interest" techniques. We also observed the occupant indicating to the designers the width of the virtual walkway by gesturing. This shows the benefit of the immersive experience created in Dollhouse VR. It was rewarding to see the participants design the layout by taking various aspects into account such as business and service. This shows that Dollhouse VR works as a communication medium, connecting various types of experts, which is particularly important for architectural-scale space design where various types of expertise are necessary such as architecture, electrical, interior/exterior design, air conditioning, safety, legal, and marketing. or us, it is necessary to play with them.

Likewise, a participant of the case study commented that "I thought that this system can be used by those who are not familiar with blueprint, like managers and servers who work on the actual restaurant," and "it allows them to join the discussion with expert of architecture." This indicates that the importance of the virtual experience, in particular the first person view gives the users to experience the virtual environment that represents the blueprint in 3D, and users can manipulate the object in the virtual immersive environment. So far the designer and the architect was the only expert who can touch the design process of architecture, but the dollhouse VR system realized the fair discussion to include any kinds of business background.

Dollhouse VR can also be applied in other areas. For example, it might be useful in sports for game preparation. The team members and manager/coach could discuss team formations for different plays. The director could specify a formation and the actions of the players, and the players could perform accordingly in the immersive environment wearing HMDs. The players could then give feedback for improving the formations. Dollhouse VR might also be useful for creating multi-player immersive video games.

Our Dollhouse VR system is a proof-of-concept implementation so that there are many venues to do for practical application and usability. First, we confirmed the effectiveness of the dollhouse VR system as a collaborative design tool with a user study and a case study, however even though participants used the giant finger and see-through ceiling for communication, we did not prove the effectiveness of these two functions as a scientific finding. Formal user study and/or experiment is necessary for validating the cognitive effect of these interaction technique. Second, only 2D pointing is currently supported for both the occupant and designers while 3D pointing is preferable. Third, it is difficult for the occupant and designers to make eye contact through the see-through ceiling. Eye contact is essential for communication, so further investigation is needed to support better eye contact. Finally, the avatar is simply a typical body size; we plan to implement a feature enabling the size of the avatar to be adjusted to match that of the occupant.

7 CONCLUSION

We presented a collaborative design system using virtual reality facilitates asymmetric collaboration among users with different asymmetric viewpoints in the design of spaces. A preliminary study demonstrated that our system enables users with and without a head-mounted display to intuitively communicate. A case study showed that it works well to some extent in supporting discussion among professionals with various types of expertise who are working on the design of a space. They also revealed that the VR system should satisfy additional constraints specific to design discussions, such as providing a high level of scale accuracy. We plan to continue the development of this system and test it on various design tasks.

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