Couples Designing their Living Room Together

a Study with Collaborative Handheld Augmented Reality

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ABSTRACT

In this paper, we investigate the use of Augmented Reality for users designing together. We present a design application that runs on multiple synchronized and spatially aware tablets to support couples making interior decisions in and for their future living room. Based on the prior art into collaborative design, we suggest a novel design interface that deals with situated design and supports virtual workspaces. We asked six couples to design together with our prototype and analyzed their design process, the roles they took, and how they communicated. The results suggest that the social practice of couples designing in and for their home differs from professional design teams and involves more than just positioning furniture in space. We use the design, the prototype and the study to discuss implications for spatial in-situ tools concerning intimacy, collaboration, and design process. The findings are useful for future applications that deal with collaborative applications for casual users.

CCS CONCEPTS

• **Human-centered computing** → **User studies**; **Collaborative interaction**; • **Computing methodologies** → **Mixed / augmented reality**;

KEYWORDS

Interior Design, User Study, Augmented Reality, Multi User

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1 INTRODUCTION

Appropriating and routinizing objects to our needs is an essential skill in daily life. This includes furniture layout, configuration, and customization, and is beneficial for the quality of life (e.g. increased comfort, efficiency) and safety, such as for small children, and in workplace ergonomics. However, they also require users to take part in a design process as they adapt the products to their needs, and this can be problematic. To understand the practice of object use in the home, several ethnographic studies looked into how families appropriate items [12, 38, 41], use technology [23], and buy furniture items [27, 39]. These studies reveal that customization is a process that happens over time and starts with identifying a need and continues with information gathering, prototyping, and evaluating products during use [3]. This process is required because people and families do not fully understand what they need before they buy the product and have it in use, or before they change their routine.

In addition, decision making and use is often shared within families and between spouses [35, 36]. Family members take various roles in the process that leads to a purchase. Roles include those of information gatherers, influencers, decision makers, and purchasers [34]. Furniture is shared and part of daily routines [11]

Figure 1: Couples designing together. Overview and AR mode being used simultaneously (top), two workspaces being actively used to compare different designs (bottom).

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and living rooms often serve multiple purposes, such as for eating, watching television, and storage. Family members might have unique and conflicting requirements.

Several applications are available to help users customize products and aid users to plan and layout interiors in their homes. However, these often web-based applications take place on a PC, phone, or tablet. Augmented Reality applications, such as from Ikea, focus on visualizing a single furniture item in a room. Currently, there is limited understanding and technologies supporting these intimate design collaborations involving couples and families.

Therefore, in this paper we look into how family members could work together when they are layouting their living room and we try to understand them as "designers" making a new design. We developed an Augmented Reality (AR) application that runs on multiple tablets to let users prototype directly in their rooms and see this as an equivalent for a large shared workspace. We conducted a qualitative user study in which we asked six couples to make a layout with AR tablets. We observed how couples communicate and make joint decisions regarding their home. Within the limitations of the small study that we ran in the lab, we make the following contributions for future AR layout design applications that focus on households: 1) Applications need to consider the design phase as we observed different behavior between couples exploring ideas and executing designs. 2) Couples design based on functionality and think in areas such as a "tv area" or "office area" rather than in furniture items. 3) Couples mostly work on the same thing but take unique roles. 4) Multiple view modes are important in situated design and specifically in case of a small space such as a Korean apartment.

2 RELATED WORK

In the case of interior design, several online applications aim to aid with the configuration of kitchens [20] or storage modules [9]. Research into interior design applications looks into optimizing placement of furniture [42]. For instance, a pairwise relationship between a couch and television results in rules that deal with distance, angle, and a clear line of sight. Other work [30] extracted criteria from visual composition rules found in interior design books. Based on a layout made by the user, their system provides suggestions such as for alignment. However, although some of these systems provide 3D visualizations, most toolkits are 2D and web-based and do not relate to the actual situation of the users.

2.1 Situated Visualization

Another related research looks into situated visualization. For instance, to enable users to draw new objects in photos and reconstruct the object's 3D geometry from the perspective in the photo [26]. In architecture, Insitu [32] lets users sketch on-site, situated in the context of the surrounding environment. The context is captured from multiple sources, such as elevation data and photos, to generate a design. Several projects let users design with handheld tablets with spatial awareness to directly interact with the physical world [13]. T(ether) [24] is one such tablet-based system that offers direct manipulation of virtual objects seen through the device. Situated modeling [25] employs a first person experience to enable users to design furniture through stamping primitive shapes in the use environment using an Head-Mounted Display (HMD) and tracked hand-held tools. These projects suggest that people benefit from a situated visualization for creating objects in the living room, but do not support collaboration such as making layouts together.

2.2 Collaboration

Most AR projects with the aim to support collaboration are found in games. For instance, the Invisible Train [37], played on multiple tablets, or Mano-a-Mano [5] uses Spatial Augmented Reality for users to play games. A few projects suggest that users could benefit to employ AR in the living room [7, 33] to help users in their configuration task. Therefore, we look into an AR application for families jointly configuring furniture in their living room.

Since professional designers often work in teams, we looked into collaborative design tools. Professional collaborative tools have a shared and often large workspace such as a whiteboard [10, 16, 18, 29]. These workspaces support designers to layout ideas spatially, point at things, draw, and annotate together, and unifies communication and task space [21, 22]. Gutwin and Greenberg [17] stress the importance of awareness in such collaborative user interfaces. Designers fluently switch between synchronous and asynchronous work, between working together on a single aspect of the design [10] and breaking away to explore ideas by themselves [16]. Team Storm [18] for instance, allows designers to sketch in either private spaces or public spaces, with tools to provide feedback on others' sketches. When returning from independent work, designers must synchronize their mental models of the design by explaining their work to others [16]. The group may need to integrate separate ideas into a new unified design. This process involves combining parts of several sketches or generating a new design that borrows conceptual aspects. We support multiple design spaces to let family members explore ideas on their own, before combining ideas into a shared design.

2.3 Collaboration in the Living Room

We build on ethnographic studies of people's homes that indicate differences between design for professionals and for use in households, as domestic life is not characterized by a shared objective but by a diverse range of contrasting interests [8]. This surfaced in previous studies, where we found that one partner in a couple typically makes the decisions and that spouses often compromise. However, studies that let couples or families design together [7, 27], suggest that intimacy may play a role. Final decisions are always made together and there are differences between young couples who still explore each other's preferences and old couples seasoned in decision making. We focus this paper and study on how couples share ideas, reach a shared understanding, and jointly execute their design.

3 DESIGN

We created a multi-user application to let couples design layouts together in their living room, called ShareDesign. The application was developed for tablet-based AR (Project Tango technology [14]). Similar technology will be embedded into the next generation of smartphones ([2, 15]). Handheld AR is video see-through and

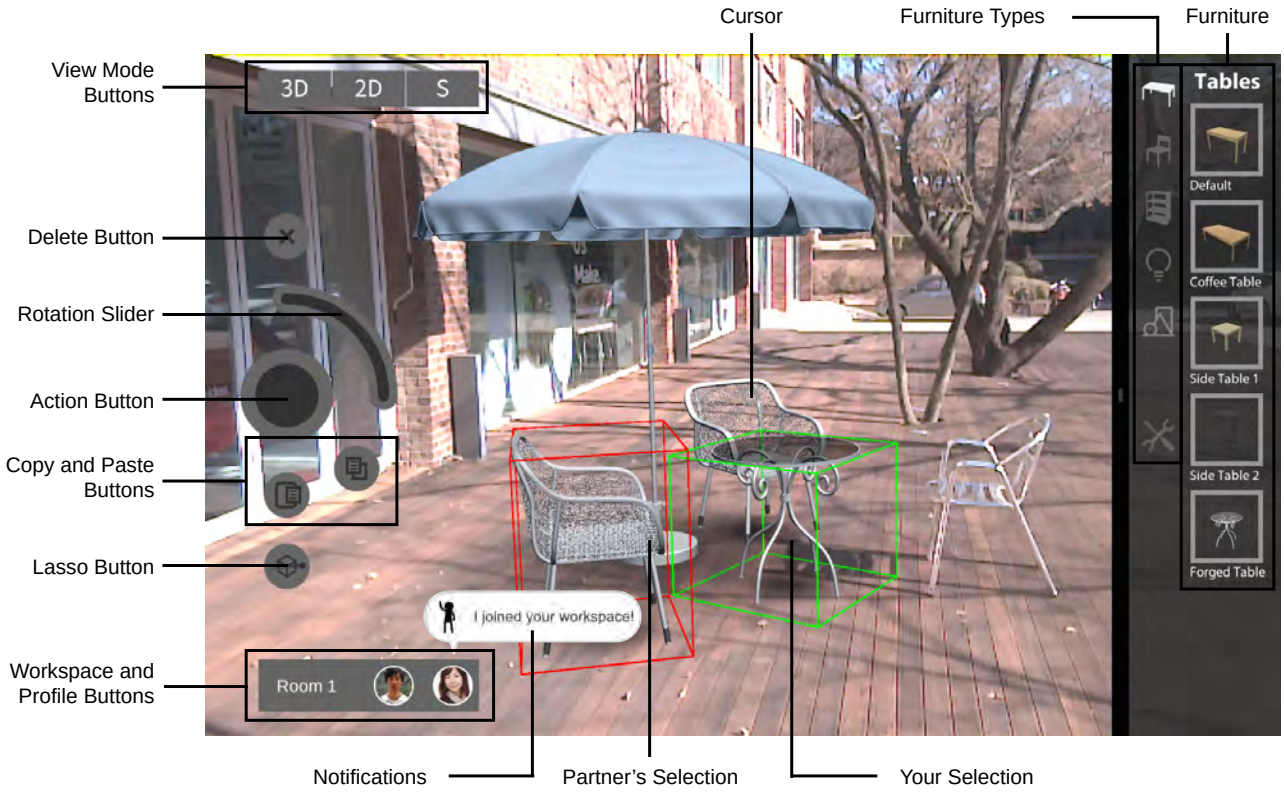

Figure 2: The UI of ShareDesign, showing a collapsible side menu on the right-hand side and a collaboration menu on the left-hand bottom edge. Two virtual objects are placed in the real world and selected, with the local user's selections highlighted in green and their partner's selection in red.

augments the camera image with virtual objects. We designed a graphical user interface on the edges of the video, which is depicted in Figure 2.

We implemented standard features for layouting a space that we extracted from the related work [7, 28, 31, 42] and from existing layout applications [4, 19], such as spawning, selecting, moving, and deleting. When items are spawned or posed, they "snap" context aware: on the floor, walls, or ceiling, taking into account collisions from both physical and other virtual objects. Floor items, like tables and accessories, can also be stacked on top of each other [6]. Moving the furniture items on the bottom of the stack also move the items above it. We included a library of common items like chairs, tables, lights, and miscellaneous decorative items such as a TV and rug. We intentionally made the furniture neutral looking and did not include manipulation of color or materials to let participants focus on layouting tasks.

3.1 Multiple Workspaces

The related work that deals with professional teams suggests that designers utilize multiple design representations to explore and visualize ideas. To facilitate collaboration, we implemented the concept of workspaces [7] which utilizes a single coordinate system shared between the tablets that allows content to be synchronized over a network. Couples can work in a shared workspace, branch off to explore a design on their own, or merge multiple design ideas in a single workspace. An example usage of workspaces can be seen in Figure 1. Users can create several different furniture layouts in the same physical space. Furniture can also be group selected and easily copied between workspaces.

Once furniture is placed, it can be manipulated by either user. When both users are working in the same workspace, we indicate the selections of the other user with a red highlight which contrasts with the local user's green highlight, as shown in Figure 2. In that way, we expect users to be better aware of each other [17], but also that they use selection as a means to virtually "point" at objects in order to draw attention to them.

The workspace icon on the bottom of the screen appears when a partner joins the project, showing their profile image and whether or not the users are in the same workspace. If they are in different workspaces, pressing their partner's profile image brings them into their partner's workspace. Couples can show their partner their designs by inviting them into their workspace or by physically showing them their screen. When users change workspaces, create workspaces, or take virtual snapshots, others will be informed through notifications. Speech bubble style notifications were used to facilitate a more personal and intimate experience. Both the workspace icons and notifications are visible in Figure 2.

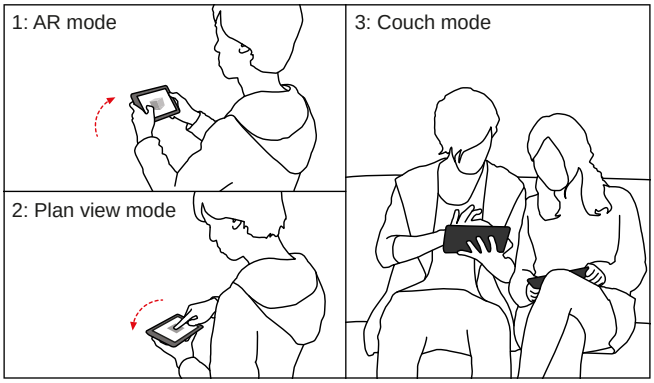

Figure 3: Tilting down from the AR mode (1) automatically changes the view mode to the plan view mode (2). While designing, couples can make interactive photos and then modify them at a later time and place through the couch mode (3).

3.2 Spatial Understanding

The Tango tablets have a relatively small screen size (15.5cm x 9.5cm) which is sufficient to position a single furniture item at a distance, but less suitable to understand the spatial impact of several items in a room. Therefore, to give users different perspectives from which to obtain an understanding of their spatial environment, three view modes have been implemented:

AR Mode is an engaged mode in which the user moves around and observes the virtual furniture through the tablet as a real size, situated preview. The furniture is spatially registered and augmented in the camera feed of the tablet. **Plan View Mode** is a top-down, map-up view of the room [40] that shows the furniture and the positions of the users. The view can be zoomed in, rotated, and panned with multi-touch gestures, similar to mapping applications. **Couch Mode** is for reviewing and manipulating the virtual geometry from a "couch" or other location. When making designs in the AR mode, users take virtual snapshots of the geometry. These snapshots can be used later to manipulate furniture in a situated context even when not physically located in the actual environment.

While informally testing the application, we observed that users often angle the tablet in a horizontal orientation when utilizing the plan view mode as opposed to upright orientation in the AR mode. Based on this behavior, we toggle between the AR mode and plan view mode by physically tilting the tablet, as shown in Figure 3. An additional benefit is that holding the tablet horizontally reduces arm fatigue [1], or gorilla arm, when using the AR mode for an extended period of time. Figure 1 shows one couple where one person uses the AR mode to survey the scene while the other uses the plan view mode to make changes.

4 USER STUDY

The user study we conducted only captures a single moment in time, whereas in practice the purchase and design process evolves over time with multiple synchronous and asynchronous design sessions. Therefore, we designed the study to force couples to engage three typical situations that they are likely to encounter: 1) exploring ideas individually, 2) explaining ideas to each other, and 3) designing together.

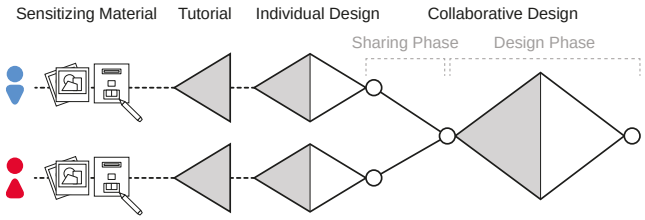

Figure 4: We asked participants to complete sensitization material prior to the user study. Through the individual design, they identified ideal design. Through the sharing phase, a shared understanding is uncovered, which is further developed in the collaborative design phase. This resulted in a final design ideal for both participants.

4.1 Setup

The user study was held in an office space that had the size of a typical Korean apartment living room. It also contained a glass wall to a patio, which represented the common veranda area. To resemble an apartment, we placed a rug in the center of the room. Two video cameras were set up in the opposite corners of the room to record the couples' activities.

In addition, we gathered metrics from the tablets to determine what the participants were doing, such as the position and orientation of the tablets in 3D space and the user's actions on the GUI. We used this data to create movement graphs, as seen in Figure 8, simulate actions, and extract insights.

Participants were recruited through online social networks and university postings. We selected 6 couples (N=12, mean age=25) who had dated for at least 6 months or had finished their bachelor degree. Such conditions were applied to recruit couples with mature relationships who would thoroughly discuss their future living room designs. Each couple was compensated 30,000 KRW (25 USD) for their time.

4.2 Procedure

Designing a shared space is not a regular activity for all couples. It requires planning and testing to understand their own preference as well as the other's. Therefore, two days prior to the study, we gave sensitizing materials to each participant to prime them for the study. The first day activity required each participant to obtain pictures of their ideal living room design. The second day tasked them to draw their ideal living room from a top down perspective and submit it before the user study.

The main user test, as shown in Figure 4, was conducted with one couple at a time and took about an hour each. The test started with an introduction and a tutorial before the two main activities: individual design session followed by a collaborative design session, and finally a post interview.

In the tutorial, we introduced the main features of the application with a live demo and diagrams highlighting the interface elements.

Then we gave each participant a tablet to practice the general functions for 10 minutes each. They were asked to perform the main functionalities such as spawning objects, manipulating objects, copy and paste, lasso selection, changing a workspace, and using the couch mode.

The tutorial was followed by an individual design session. We asked each couple to design their future living room as if they were to share an apartment together and we informed them that they would collaborate with each other with their individual designs. The session was conducted with one participant at a time for 10 minutes. The couples decided who would go first and the other partner took a rest in a separate room.

Following both individual sessions, the collaborative design session took about 10 minutes and started with a live demonstration of the collaborative features. To force them to share each other's designs, we asked them to take a few minutes to introduce their individual designs to their partners. Figure 5 shows two examples of how the couples interacted with each other during the collaborative design session.

The post-interview was held to reflect on the collaborative design session. The results of the individual and collaborative design sessions were accessible for reference using the couch mode on the devices.

5 RESULTS

All couples were satisfied with their layout designs, but some complained about the limited collection of furniture which did not satisfy their aesthetic needs. Most participants fluently used the application after the demonstration and practice session, except for two females (couple 4 and 6) who admitted that they were not familiar with using tablet-based applications. However, with the help of their partners, their ideas were included in their shared living room design. During the collaborative design session, all couples actively communicated with each other to express their needs and understanding of the room.

5.1 Areas rather than Objects

We observed that couples discuss their designs in terms of functionality and in items grouped together in what we call areas. We observed all couples creating two or three different areas for their future living rooms. These areas are depicted in color in the timeline of the design process (Figure 7). As shown, all couples made adjustment to areas in an iterative process. Overall, six different areas were identified: A**TV area** was the most common area and included a sofa. A**relaxing area** was usually created near the foldable glass doors, which was understood to be a veranda. Typically consists of armchairs and a small table. A **reading area** had bookshelves and armchairs for reading. A **working area** had desks and chairs. A **storage area** filled with storage boxes. A **bar area**: which was explicitly named and represented by one couple by a table and a bookshelf.

5.2 Design Process Flow

In the beginning of the collaborative design session, the partners presented their own design by areas and focused on the key objects in each area. While one person was presenting, the other person followed their partner's view and commented on any similar or different object placements and shared use scenarios in the area.

Figure 5: Couples utilized various collaborative styles to design their living rooms. Some couples interact not only through the tablet, but through physical gestures to draw attention to specific parts of the design (top). Other couples view the design from different angles and give feedback (bottom).

Participants used two different techniques to go about making a shared design. The first method was following one partner's design (Couple 1, 3, and 6). After comparing each other's design, the couples chose the design with better appearance or functionality. For instance, both male and female participants from the couple 1 created a similar TV area and used the veranda area in different ways (Figure 6 C1). As the female participant preferred the male participant's relaxing area, they created their final living room design based on the male participants design and made final adjustments together.

Another observed style consisted of creating a new layout by combining different areas from the individual designs (Couple 2, 4, and 5). Among the different areas that each participant created during the individual design session, the couples chose the areas that they liked and combined it with a few modification. This was the case of the couple 4 who created a new layout by merging the female participant's TV area and the male participant's relaxing area (Figure 6 C4). They changed the male participant's relaxing area to match with the TV area, which was the primary area in their design.

5.3 Collaboration Styles

For better understanding of the couples' collaboration process, we laid out each participant's object manipulation, screen sharing, and edited area on a timeline (Figure 7). We observed two distinctive collaboration styles such as working as one and dividing tasks.

When the couples were exploring their ideal living room design, they worked as one to share ideas and manipulated objects by taking turns. While one person talked about or modified the layout, the other followed either looking through own tablet or peaking at their partner's tablet. For instance, couple 4 discussed the layout of their TV area by trying out different furniture. While the male participant was manipulating furniture, the female participant observed and made comments on his manipulations.

Couples who gained a shared vision regarding their design divided tasks to execute the layout and manipulated objects at the same time. In the case of the couple 1, they jointly and synchronously manipulated furniture items within the TV area before moving together to the next area. After creating the general layout of the second area, each focused on a different area to concurrently make final adjustments. Even when they were working on different furniture, they constantly confirmed with each other to make sure that they were including their partner's opinions.

5.4 Situated Layouting

Couples continuously communicated with each other, shared a view, and moved around the room to discuss and implement their designs. As they were looking at their design through a small tablet screen, each couple took different strategies for effective collaboration, which we observed in their unique movements patterns. From the movement data shown in Figure 8, we identified three types of behaviors.

The first behavior involved moving around the edge of the room (Couple 1 and 6). These couples decided their final design right after sharing each other's design and started implementing their final design. They began their collaboration from one side of the room, but eventually they walked around the room to design their living room from different angles and not block each other's view.

The second behavior consists of moving all over the room and observed with couples two and three. Although they displayed same movement pattern, their purpose was different. Couple 2 lively discussed every furniture item they added and slowly worked to their final design. They typically walked up to the spot and discussed placements options and implications for their design. Couple 3 already confirmed their final design in the beginning of the collaboration phase. Their process was mostly executing (implementing) their design while they reviewed item placement with play-acting as if they were using with the virtual furniture. For instance, the male participant acted like he was seated on the couch while looking forward through the tablet to assess the distance between the TV and the sofa.

In the third observed movement behavior (Couple 4 and 5) participants stayed put in a single position in the room. Couple 4 actively used the plan view mode and could manipulate all of the furniture without moving around the room. Couple 5 did not use the plan view mode but they placed all the tall furniture behind the smaller furniture and did not need to move around to select or view occluded furniture. Although not moving around, both couples made a new design by combining elements from their individual designs and creating new areas.

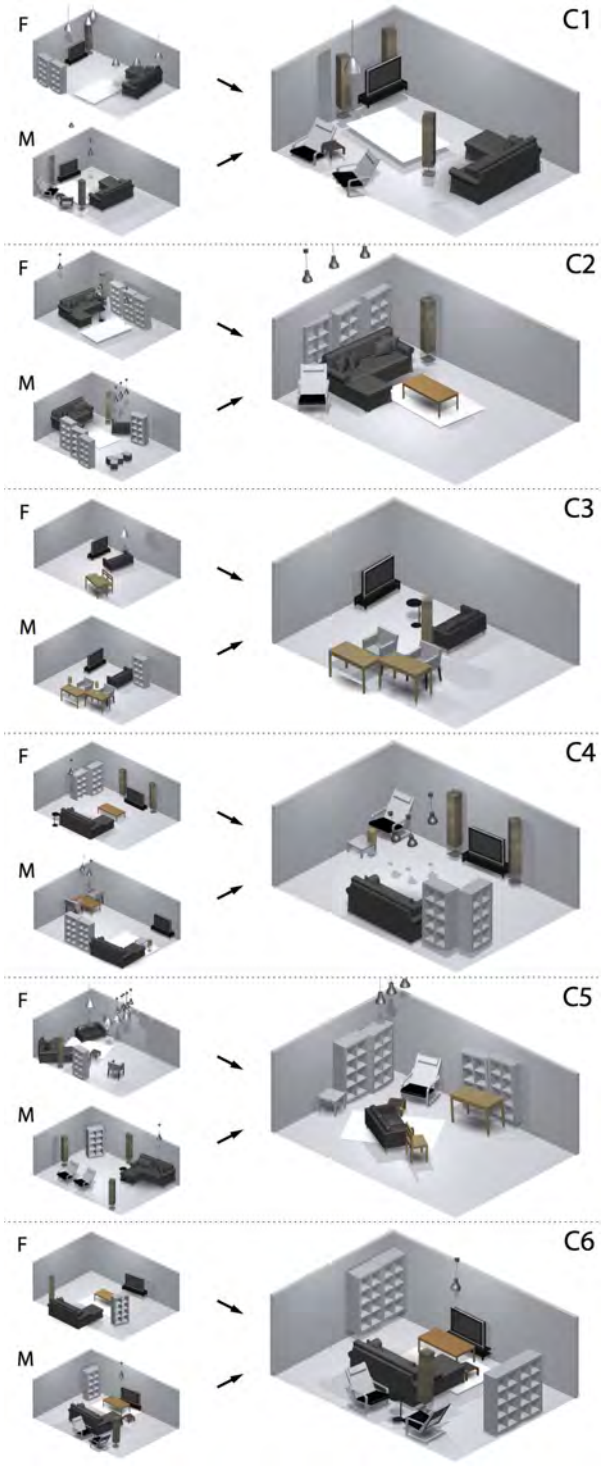

Figure 6: The smaller designs on the left-hand side are the designs from the individual session and the larger designs are the finalized designs from the couples' collaborative session. In cases like couple 4, the final design merges elements from both individual designs. On the other hand, couple 5 made a completely new design.

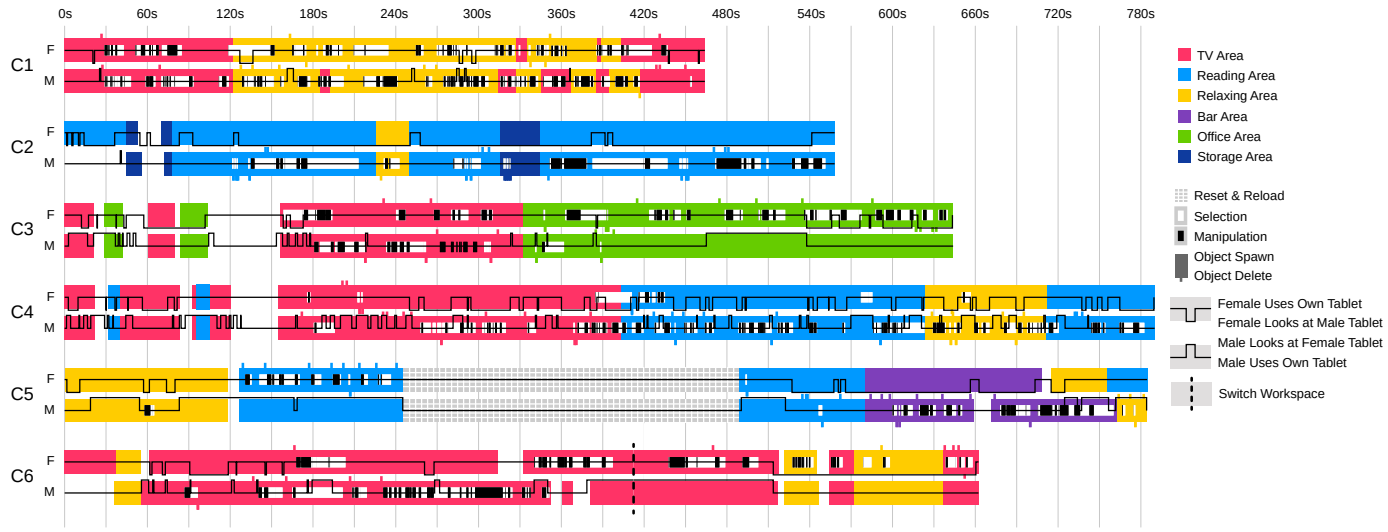

Figure 7: We visualized each participant's design activities. The colored bars represent areas where users spawned, manipulated, and deleted objects. All the manipulations and selections were depicted as black and white squares, which were used for analyzing synchronous and asynchronous design activities.

6 DISCUSSION

In this study we had 6 couples make a layout for their future living room. Our couples were young and did not live together yet and for most couples this was the first time they discussed this topic together. We realized that in practice this process takes several months of preparation where as in our case we condensed it to less than 30 minutes. However, by letting each participant explore their needs and wishes individually before making a shared design, we aimed to address a number of typical collaboration scenarios, including explaining ideas to each other, designing together, and conflict resolution. Nevertheless, the study, with limitations in mind, put forward interesting topics that are currently not yet addressed in the literature regarding Augmented Reality and how couples design together.

6.1 The Benefits of Additional View Modes

Most couples designed their living room in the AR mode since the visualization of their ideas was beneficial to their collaboration. As a part of design process, they wanted to check how much progress they have made so far, but the screen was not big enough to display the entire layout of the room at once. Therefore, the participants often stood outside of the room and tried to observe the overview of their design. For such purpose the plan view mode was helpful, even if it did not provide immersive visualization of their design. The couples who actively used the plan view mode could check their progress from where they stood and keep working without changing their position.

In our study, we used the plan view mode to overcome the limited field of view from the small screen of tablet, but there would be a need for additional view modes when we focus on different situations. Although users could observe their partners' manipulation from own screen, they often looked at each other's screen even when they were standing next to each other. In such case, a view mode designed to observe a partner's behavior would be useful. Another situation that we would consider is head-worn AR with a wide angle of view. With such technology, users would be able to observe their entire design in AR mode without stepping outside of their room. In this case the necessity of a plan view mode would need to be rethought and applied in different styles.

6.2 Using One or Two Tablets

Although we gave each participant a tablet, some couples naturally switched to using only one tablet during the entire collaborative design session. A single tablet was helpful as a shared view as many decisions were made together. During discussions both looked through the tablet holder's view. These couples often switched when one person suffered from fatigue. For example, the female participant in couple 3 gave her tablet to her partner when she felt tired after a long time in the design session. The male participant then made the final adjustments using her tablet.

Using two tablets was considered useful for couples who mostly executed their design ideas (implementation). Each user could work on different furniture at the same time and enhance their work efficiency. Another benefit of having two tablets was using each tablet for different purposes. For instance, couple 4 used one tablet for visualizing their design in the AR mode and another tablet for manipulating objects in the plan view mode.

In contrast to what we expected from professional design practice, one tablet seemed sufficient for couples because of their intimate collaboration style. This implies that future collaborative design applications for couples can be designed for collaborative use with a single device, as opposed to multiple devices. However, our research only sampled one moment in time and in reality, users may not design at the same time or place. In the case of sharing designs and spatial understanding, we found that using two tablets

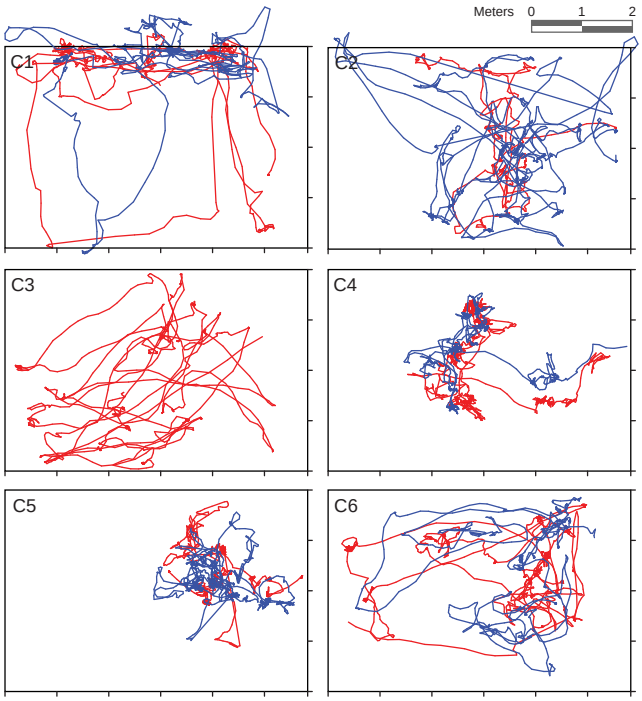

Figure 8: The raw movement data for all of the couples are represented in red (female) and blue (male) lines. The rectangle represents the room they were designing in, which most couples found an ideal area for them to design in, leaving that area briefly only to view their designs from a different perspective. Couple 3 encountered some technical errors so that the movement data for the male was not captured, therefore the video was used for analysis.

resulted in a more fluent design process. In addition, the couch mode was useful in the reflection and perhaps to bring the home to the furniture store.

6.3 Design Roles

Unlike the individual design session, not all the participants manipulated furniture during collaboration. Regardless of whether they used their own tablet or not, some users preferred to just observe their partners' manipulations and command them. We identified observer and implementer roles based on this interaction.

We believe that the collaboration was successful even with such unbalanced workload because couples do not try to divide their work equally. This is a different case compared to the professional collaboration styles indicated by Maher et al. [29] since the couples' main concern was to include each other's needs in their designs and they were willing to help each other to express own ideas. Even when the observers did not make any comments, the implementers always asked the observers' opinion before or after any modifications.

Their distinctive roles suggest that people with intimate relationships would collaborate with more flexibility and care for each other. They would require different support compared to expert design teams and applications that provide specialized functions would enhance their unbalanced collaboration. One conceptual scenario would be adding suggestive features for observers so that they would be encouraged to consider other designs while the implementers focus on creating their current design.

7 FUTURE WORK

This study is a first step towards collaborative design interfaces for furniture layout at home. Designing a living room requires preparation time and happens over a long period and so the next step is a longitudinal study to understand how couples make decisions and collaborate over time in AR.

Although we implemented the couch mode to facilitate continuous design process outside of the room, there was no need for the participants to use the feature during our study. We believe that the longitudinal study would also provide insights on the benefits of the couch mode and non co-located collaboration as well.

Finally, in our study we observed couples as one type of people who have intimate relationships and observed their own unique dynamics during collaboration. We learned that intimate relationships affects people's collaboration and expect that there would be different roles and processes if it was between parents and children or siblings. Their intimacy would be different from couple's and it would be worth observing as they are key stakeholders of a living room.

8 ACKNOWLEDGEMENTS

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