

CO-LOCATED COLLABORATIVE INFORMATION-BASED IDEATION
THROUGH EMBODIED CROSS-SURFACE CURATION

A Thesis

by

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ABSTRACT

We develop an embodied cross-surface curation environment to support co-located, collaborative information-based ideation. *Information-based ideation* (IBI) refers to tasks and activities in which people generate and develop significant new ideas while working with information. *Curation* is the process of gathering and assembling objects in order to express ideas. The linear media and separated screens of prior curation environments constrain expression.

This research utilizes information composition of rich bookmarks as the medium of curation. Visual representation of elements and ability to combine them in a freeform, spatial manner mimics how objects appear and can be manipulated in the physical world. Metadata of rich bookmarks leverages capabilities of the WWW.

We equip participants with personal IBI environments, each on a mobile device, as a base for contributing to curation on a larger, collaborative surface. We hypothesize that physical representations for the elements and assemblage of curation, layered with physical techniques of interaction, will facilitate co-located IBI. We hypothesize that consistent physical and spatial representations of information and means for manipulating rich bookmarks on and across personal and collaborative surfaces will support IBI. We hypothesize that the small size and weight of personal devices will facilitate participants shifting their attention from their own work to each other and collaboration.

We evaluated the curation environment by inviting couples to participate in a home makeover design task in a living-room lab. We demonstrated that our embodied cross-surface curation environment supports creative thinking, facilitates communication, and stimulates engagement and creativity in collaborative IBI.

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1. INTRODUCTION

People engage in everyday *information-based ideation*, often in collaboration with close relatives at home. That is, they develop ideas, such as planning a weekend, vacation, or living room makeover, with information serving as stimulus and support. During ideation processes, people engage in curation, which involves gathering, assembling, and annotating information from various sources to form meaningful exhibit. They develop understandings of curated information elements, associate them to form relationships, become inspired, and generate new ideas. Networked devices are widely used to curate from the Web. However, prior curation media and tools constrain expression. Further, for collaborative knowledge work, mobile devices, although powerful in their computing capabilities, become isolated by the absence of natural mechanisms for sharing information.

We developed an embodied cross-surface curation environment to help co-located people engage in creative thinking, communication, and collaboration with others in everyday ideation tasks using multiple devices. It utilizes information composition of rich bookmarks as the medium of curation. The visual representation of elements and the ability to combine them in a freeform, spatial manner mimics the manner in which elements appear and can be manipulated in the physical world. Visual representations utilize the sensory system in manner more like physical objects than solely textual ones do. The metadata and linking of rich bookmarks takes advantage of the digital world capabilities of the world wide web. We also designed embodied interaction for connecting personal surfaces to the collaborative surface to facilitate rich bookmark sharing. Our curation environment supports ideation through: gathering rich bookmarks on personal surfaces on tablets; exchanging rich bookmarks

between personal surfaces and the collaborative surface, a large screen display; and assembling rich bookmarks spatially to form a meaningful information composition on the collaborative surface. This environment affords communication and flexible body orientation and spatial organization of participants during collaboration.

We evaluated the curation environment by inviting couples to participate in a home makeover design task in a living-room lab. We hypothesize that the integration of physical representations for elements of curation and the assemblage of curation, with physical techniques of interaction within collaborative curation environment and between personal curation environments and the collaborative environment will facilitate collaborative IBI. We hypothesize that consistent physical and spatial representations of information and physical and spatial means for manipulating rich bookmarks on and across personal and collaborative surfaces, will support IBI. We hypothesize that the small size and weight of personal devices will facilitate participants shifting their attention from their own work to each other and collaboration. We evaluated the curation environment by inviting couples to participate in home makeover design tasks in a living-room lab.

1.1 Information-based Ideation and Curation

Ideation is the process of generating new ideas. Kerne *et al.* defined information-based ideation as *the performance of open-ended tasks and activities in which people generate and develop new ideas, while digital content serves as stimulus and support* [1]. Information-based ideation tasks include “imagining, planning and reflecting on a weekend, vacation, outfit, living room makeover, paper, internship, thesis, design, campaign, crisis response, career, or invention.” Information-based ideation goes beyond understanding facts from collected content. It also involves analyzing and synthesizing information to generate new ideas.

During information-based ideation processes, people develop creative products, which can be called *curations* [2]. *Curation* is the process of assembling content into meaningful exhibits, which are meant to be used as stimulus and support for thinking. Curation involves gathering, assembling, and annotating digital found objects [3]. Assemblage of digital objects typically takes forms such as the linear feed and board.

Curation in the physical world is open-ended and freeform. A curator can gather objects and information and organize them into a presentation in any manner. At the same time, digital curation is constrained. The way each gathered element becomes represented is dictated by the underlying interactive system. The manner in which elements can be put together is likewise constrained. Thus, digital media of curation can be understood on two levels: elements and assemblage [1]. The first is a medium of curation of individual information elements. The second is a medium of assemblage of these information elements into some sort of whole.

For instance, *Pinterest* is a popular website digital curation on the Web [4]. Pinterest use Pins as medium of elements. Pins are visual semantic image or video clippings with metadata curated by users from other Web pages. The medium of assemblage for Pinterest is a first-in, first-out constrained grid form, known as a board. Pins are organized a fixed chronological order, based on the time they are added to the board. Despite the constraints on organization, the rich visual forms of Pin and board support users engaging in *everyday ideation* through digital curation on Pinterest [5], meeting personal and social needs.

1.2 Curation Medium: Information Composition of Rich Bookmarks

We sought to develop a medium and environment for curation that would support couples engaging in the information-based ideation task of home makeover design,

in a natural manner, corresponding to how they experience, interact with, organize, and design the physical world, but the advantages the digital world provides for representing information. We developed an environment to support co-located, collaborative curation for everyday information-based ideation. In our environment, *rich bookmark* is the medium of elements of curation, and information composition is medium of assemblage. A rich bookmark combines a visual image or text clipping and textual metadata, derived from the source web page [6]. It includes a link that affords re-finding the web page its clipping was gathered from. In accordance with principles derived from cognitive psychology [7] and HCI [8], representing information as image clippings with metadata facilitates understanding and interaction.

Information composition as a medium of assemblage enables putting rich bookmarks together as a visual semantic connected whole [6, 9]. It emphasizes freeform spatial organization of curated elements and expression. Instead of using formal grid or tableaux based organization, information composition allows users to express relationships among the information by changing spatial and visual properties of rich bookmarks, such as position, orientation, size, translucence, and proximity. By affording representing rich bookmarks spatially as a visual semantic connected whole, information composition promotes creative cognition of relationships among curated rich bookmarks, which is a key to ideation [9, 10].

This study utilizes information composition of rich bookmarks as the medium of curation. The visual representation of elements and the ability to combine them in a freeform, spatial manner mimics the manner in which elements appear and can be manipulated in the physical world. Visual representations utilize the sensory system in manner more like physical objects than solely textual ones do. The metadata and linking of rich bookmarks takes advantage of the capabilities of the world wide web, in the digital world.

We developed a curation environment to support co-located users collaborative engagement in information-based ideation. In prior research on information composition, the environment was designed for a single user, with a smaller display and indirect modalities of interaction, the mouse and keyboard. In prior research involving collaborative search, we see users engaged in an information-based ideation task, but assembling text-only creative products [11].

In the curation tool from previous studies, both the Web browser and the information composition appear on the same personal display. In our curation environment, the information composition takes the entire collaborative surface space. Users manipulate rich bookmarks in the information composition using embodied touch gestures on the collaborative surface. Users collect information independently and store them as rich bookmarks on separate, personal mobile surfaces. To facilitate sharing rich bookmarks across surfaces, we developed cross-surface interaction for connecting personal and collaborative display surfaces, and exchanging rich bookmarks between surfaces.

1.3 Cross-surface Interaction in Multi-display Environment

Weiser envisioned people working with computing devices of different form factors, connected wirelessly in a collaborative environment [12]. The proliferation of powerful mobile computing devices and large displays presents the potential for synergistic integration to support collaborative activities involving sharing information. Large, high resolution displays, such as HDTV television sets, support co-located collaboration. Mobile devices provide private interactive computing resources. Nacenta *et al.* referred to interconnected interactive devices as ‘multi-display environments’ [13]. Kerne *et al.* coined *trans-surface interaction* to refer to those interactions in multi-display environments that involve manipulating information objects across

devices with sensory input modalities, such as touch, pen, and free-air [14]. Cross-surface interaction features user experiences of moving and manipulating information across interactive surfaces, providing a sense of continuity.

A compelling need for cross-surface interaction is to integrate private mobile devices with a large surface for collaboration. Users' personal working surfaces on the mobile devices and the collaborative surface are physically discontinuous. A *portal* is a transitional space that affords moving between larger spaces [15]. Problems for interactive experience design include how to initiate a portal connecting a mobile device and a collaborative surface, where to position the portal, and how to move objects through the portal. People often move around a collaborative surface [16], and they gather dynamically [17]. This requires dynamic capabilities for spatially mapping mobile devices and user presences around a collaborative surface. We developed *embodied cross-surface interaction techniques*, which use an array of tangible NFC tags on the periphery of collaborative surface to afford robust, simple cross-surface portal initiation and relocation.

We extended the collaborative surface, a 55" HDTV flat-screen display, with array of NFC tags on the periphery of the display. These tags function as tangible entry points that invite interaction [18]. They are always visible to a user, available for making the connection between a mobile device and the collaborative surface through touching a tag with the mobile device. They extend the interactive space of the collaborative surface, without using display pixels, providing persistent visible affordances for connecting mobile devices to positions on the collaborative surface. Touching a tag with a mobile device initiates a pair of associated cross-surface portal affordances on the mobile device and the collaborative surface, mimicking the action of physically bonding two objects. We designed portals to enable rich embodied means for manipulating information objects such as rich bookmarks on and across

displays for co-located collaborative tasks.

1.4 Embodiment in Cross-surface Interaction

We embody cross-surface interaction by leveraging spatial relationships among surfaces and human bodies. People’s understanding of how things work depends on how their bodies operate in space [19, 20]. Spatial relationships and visual properties help people mesh their intentions with affordances. We based our design of embodied cross-surface interaction for manipulating information on prevailing mental models for exchanging physical objects.

Cognitive scientists have shown that mental models are embodied [19, 20, 21]. People mesh their ideas with affordances to accomplish action-based goals. Affordances are the perceivable and actionable properties that an object offers us to act on it [22]. Air affords breathing and a chair affords sitting. It also makes sense that a rock can be used as a hammer, or a paperweight because we gain our experience and knowledge through our bodies so we know that a rock is made of hard and heavy material. In this case, our embodied mental model tells us that the hardness and the density of the rock afford using it as a hammer or a paperweight.

Heidegger called the proximate entities that we use in our everyday interaction with the world *equipment* [23]. We use an equipment not because it is there, but to accomplish tasks. A rock becomes equipment when we use it as a hammer. Thus, we can describe an equipment with its roles in the tasks, or their ‘in-order-to’s. Heidegger argued that our everyday dealings in the world are guided by *engaged familiarity* with the equipment rather than cognition of the equipment. We obtain engaged familiarities with equipment through practice. The ‘readiness-to-hand’ property of the equipment, instead of ‘presence-at-hand’ is what makes the equipment suitable to accomplish tasks. When we use ‘ready-to-hand’ equipment and get familiar with

them, the equipment withdraws into the background and we focus more on the work, the tasks and the goals that we are accomplishing, instead of the tools and materials that we are using. On the contrary, when the equipment is *unready-to-hand*, we have to focus more on the equipment itself.

Well-designed interaction techniques can increase technology’s ‘readiness-to-hand’, better affording ‘in-order-to’s. To design embodied cross-surface interactions, we investigated how people routinely operate objects in physical space. Invoking Kerne et al’s method of culturally based design [14], we mimicked ready-to-hand embodied practices with physical objects to accomplish similar goals in digital space. Users take advantage of engaged familiarities they obtained in operating physical objects, and apply them in the digital space. Thus embodied interactions reduce the cognitive load of learning and using the technology. Users should focus on the goals that the tools are build to accomplish instead of the technology. Our design goal is to make using technologies become secondary, in consuming participants’ attention, to engagement in the task at hand.

In ubiquitous computing environment replete with smartphones, tablets, and personal computers, interacting with computers often occurs in conjunction with other non-computing activities, including communicating with other people. The goals of the interface design of ubiquitous computing are thus different from conventional personal computers. Abowd and Mynatt defined *natural interfaces* as interfaces that “*facilitate a richer variety of communications capabilities between humans and computation*”. Natural interfaces “*support common forms of human expression and leverage more of our implicit actions in the world*” [24].

In our study, we built natural interface that affords embodied cross-surface interaction, and facilitates both human-to-computer and human-to-human communications. The goal of our embodied interaction design is to assist information-based

ideation and communication between collaborators, and not to overwhelm them. The embodiment of connecting display surfaces, manipulating curated rich bookmarks on and across surfaces leverages Heidegger’s notion of engaged familiarity with our implicit actions in the world. For instance, we usually move two physical objects close to each other to make contact in order to connect them or build a relationship, i.e. holding hands. To initiate the communication between personal surfaces and the collaborative surface, we built an embodied devices connection interaction based on this natural gesture. To share information objects from mobile devices to the collaborative surface, users drag them towards the portal on the top edge of the mobile device. Moving fingers and arms away from the body creates a sense of ‘send-away’. Information objects slide out of the mobile display and onto the collaborative surface, giving visual feedback of the transfer. Similarly, to move information objects from the collaborative surface to mobile devices, users drag them towards their portals on the collaborative surface that is close to them. Moving fingers and arms toward the body creates a sense of ‘bring-close’.

1.5 Home Makeover Design Task

To evaluate our embodied cross-surface collaborative curation environment design, we invited couples of an intimate relationship to collaboratively design makeover plans for shared living space using our curation environment. Home makeover planning is a realistic and significant task for couples. Each couple lives in a space for extended period of time, and so engages in defining and redefining how that space is furnished and organized. Many participants already needed to engage in designing a makeover for part of their home prior to our user study. Couples in intimate, romantic relationships spent significant amount of time together. Thus, they had high stakes in designing their shared living space.

Home makeover designing is an information-based ideation task that involves curation. In a common makeover design session at home, couples collect and organize information in a meaningful way to specify and express ideas. They have conversation, get influenced by the curated information, and generate new ideas. In this iterative process, each couple may or may not have similar needs and requirements for the design. Their aesthetic opinions often vary. Thus, designing shared living space that pleases both partners requires active communication between them. The communication includes discussion, negotiation, as well as compromising.

The home makeover design task is also an ‘intimate collaborative’ task due to participants’ relationships. Moss and Schwebel [25] proposed a multi-dimensional definition of romantic intimacy as: *“Intimacy in enduring romantic relationships is determined by the level of commitment and positive affective, cognitive, and physical closeness one experiences with a partner in a reciprocal (although not necessarily symmetrical) relationship.”* The intimacy between couples with romantic relationships (especially the ones with long-time relationships) tends to have high level in all the five facets: mutuality, affective, cognitive, and physical closeness, and commitment. To achieve good results in a collaborative, information-based ideation task, communication via verbal and body languages are as important as, if not more important than the technologies used. During their romantic relationships, couples form personal verbal and body language to express special meanings. They already established their mutual understanding of these unique ways of communications.

In the embodied cross-surface curation environment, each participant used a tablet to browse and gather ideas and information from the Web. They then shared the gathered information to the collaborative surface, a multi-touch big screen collaborative surface, via embodied cross-surface interaction. Together, the participants designed the home makeover plan by making an information composition with the

shared information on the collaborative surface. We hypothesized that the embodied cross-surface curation environment would enable participants to give more attention to face-to-face communication, and thus to directly engage in their personal relationships.

1.6 Communicative Behaviors During Co-located Collaboration

Common communication methods during collaboration include verbal communication, eye contact, and body language. Interactional sociolinguistics studied the patterns of communicative behaviors by analyzing the gaze-direction and spatial organization of collaborators in naturally occurred co-located interaction [26].

Gaze-direction is the direction a person looks at during face-to-face communication. Gaze-direction has multiple functions during conversation. Monitoring gaze gathers information about how another person behave during the conversation. Regulatory / expressive gaze signals a participant's intentions and expectations to her partner. Eye contact or mutual gaze between two people also contains significant functions during a conversation. Mutual gaze indicates mutual attention. Extended mutual gaze often indicates the intensifying of the relationship between the two participants.

For the same group of people, the patterns of face-to-face interaction may be different with or without computing devices. Participants in the above study engaged in natural conversation without using computing devices [26]. However, during the cross-surface collaboration process, a participant has to shift her attention periodically between her personal display surface, her partner, and the collaborative display surface. We studied the patterns of the attention shifting in an collaborative environment using cross-surface interaction by observing gaze-directions.

Formation refers to a sustained pattern in which people group themselves. Kendon

defined a *transactional segment* as a space that a person establishes, involving other people and physical objects, in order to mutually communicate and accomplish a task [27]. Transactional segments for a group of people participating in co-located interaction often overlap, resulting in shared space among participants. An *F-formation* is a special kind of formation, in which two or more people orient themselves in such a way that there is an equal, direct, and exclusive overlapping space between them [26]. The shared, inner space is called the *o-space* in the F-formation. It is where the group of people actively cooperate. A *p-space* surrounds the o-space. This is where participants and their belongings reside. Beyond the p-space is the *r-space*. Even though there is usually no interaction directly related to the group activity happening in the r-space, participants actively monitor it. Participants adjust their upper bodies and head orientations to create shared space. Two people can form different F-formation configurations: L-shape, side-by-side, or face-to-face, depending on their activities [27].

When designing cross-device interactions, Marquardt *et al.* [28] studied the behavior of co-located people using mobile devices using F-formation. When participants used mobile devices as well as a digital whiteboard, they extended the definition of the F-formation by considering the digital whiteboard as functioning the same way as a human participant. The present research utilizes this extended notion of F-formation.

We designed the embodied cross-surface interaction to support flexible spatial organization during collaboration. Transferring information from the mobile device to the collaborative surface does not require physical contact between the mobile devices and the collaborative surface. This interaction design frees participants from needing to remain close to the collaborative surface while working primarily on their mobile devices. It overcomes the physical constraining problem observed in other

studies [29]. During the sharing phase of curation, each participant can freely sit or stand, close to or at a distance from, the collaborative surface.

The size of the mobile device makes it easy to hold it in one hand while using the other hand to work on the collaborative surface or making gestures to facilitate communication. It is easy for the user to tilt the mobile device toward nearby collaborators to share the personal surface. S/he can also position her body and tilt the device away to work more privately. It is possible for the user to hold the mobile device so that he can monitor both the mobile device and the collaborative surface.

1.7 Living Laboratories and Living-Room Labs

Couples usually engage in home makeover design sessions together at home. Thus, the task environment is different from that used for work-related collaborative tasks. Conducting the study for home tasks in a home setting is intended to help participants feel comfortable. We thought that participants would feel more comfortable and relaxed in an environment that feels and looks like home. However, conducting such experiments in their actual homes, while worthwhile, also raises problems such if participants would feel the presence of researchers as invasive in their own homes. It is also costly to set up instruments and recording devices outside of the lab.

Prior researchers created *living laboratories* to conduct human-centered investigation of ubiquitous computing systems. Study participants reside in a living room laboratory for an extended period of time, enabling more or less situated data collection. Their living laboratory had home furniture, plumbing, and appliances, in a similar layout to an apartment [30], to support authentic living experiences. A goal was to enable researchers to study the purpose of technologies from occupants' perspectives. This provided a basis for qualitative understanding of ubiquitous computing's impact on everyday home life.

In this study, we sought to achieve a similar goal, in a more lightweight fashion. The scope of our study does not require full time living. A living room is the place we thought participants would naturally conduct the study task, of home makeover design. Therefore, we only renovated one lab room into a living-room like environment, what we call a *living-room lab*. Morris *et al.* also conducted a study in a living room laboratory [31], but they did not connect their study environment conceptually to the prior work on living labs.

The rest of the thesis is structured as follows: In Chapter 2, we describe components of the embodied collaborative curation environment and our design considerations. In Chapter 3, we explore previous works in Human Centered Computing field related to our study. In Chapter 4, we describe our user study, and show the results. In Chapter 5, we discuss the result from the user study.

2. CROSS-SURFACE CURATION ENVIRONMENT FOR COLLABORATIVE INFORMATION-BASED IDEATION

We developed a new environment for collaborative information-based ideation. The components of the environment traverse and integrate layers of hardware, systems software, application software, and interaction design. A design strategy of the collaborative information-based ideation environment is utilization of rich bookmarks as the medium of the elements of curation and information composition as the medium of assemblage for curation. We connected personal workspaces on tablets with a larger multi-touch surface for collaboration. We used consistent direct spatial techniques for interaction with rich bookmarks on both types of surfaces, as for interactions between participants. This chapter presents cognitive motivation for this system design, followed by details of how components and layers work.

Prior research found that spatially manipulating clippings stimulated ideation for users of an information composition environment with mouse and keyboard GUI [32]. This motivates employment of multi-touch interaction, as a more directly spatial modality than the mouse. Further, information composition uses spatiality as the medium of assemblage for curation, in comparison with feeds, boards, and lists. Combinations of images and text have been found to promote the formation of mental models [21] and re-finding web information significant to users [8, 33]. By connecting metadata summaries of web pages with image clippings, *rich bookmarks*, as a medium for the elements of curation, are thus expected to support mental model formation and re-finding, and so add value to the collections that participants curate. Together, *these findings motivate the development of a curation environment for information-based ideation employing multi-touch as the interaction modality and information*

composition of rich bookmarks as the medium of curation.

Our collaborative curation environment provides users with personal workspaces, in conjunction with a collaborative workspace, because the absence of personal space has been shown to interfere with creativity. Personal spaces are needed because otherwise individuals fixate on what the group is doing, short-circuiting, their own creative processes [34]. Tablet computers are an obvious choice for personal workspaces in contexts of collaboration, because they are at once lightweight and powerful. They can be easily put aside when a user wants to collaborate. They afford looking over by one participant at her/his collaborator's device, yet also can be effectively hidden, with one's body, if s/he wants to turn away.

A fundamental principle of human-computer interaction design is to make components of an interface mutually consistent, and easy for users to understand [35]. The spatial use of the body to communicate and to hide or share information is consistent with the spatial manipulation of rich bookmarks in an information composition. Consistency motivates using rich bookmarks as the medium for elements of curation both in the collaborative space and in personal curation spaces. Again, spatial manipulation of clippings with metadata, through curation in the medium of information composition, has been found to support ideation [32].

Personal and collaborative workspaces on separate devices require a means for sharing rich bookmarks from the user's curation space to the collaborative one. Consistency suggests making interaction with the information spatially both in the collaborative information composition space, and for this cross-surface exchange of rich bookmarks. The mechanism we developed for exchange of rich bookmarks is based on cross-surface portals [14, 36]. A portal connects the space on one device with the space on another. We developed an embodied, spatial technique for positioning portals on the collaborative surface, using a peripheral array of Near-Field Commu-

nication (NFC) tags.

In conjunction with the portal positioning technique, we developed a simple flicking gesture for transferring rich bookmarks through a portal, from a personal surface to the collaborative surface. Again, the rich bookmark transfer technique is spatial and embodied.

We hypothesize that these layers of consistency in hardware, software, and interaction design, at the system and application levels of the collaborative curation environment, will support users in forming shared mental models and engaging in collaborative information-based ideation. Among the research questions we wanted to investigate were:

1. How do rich bookmarks as a medium for elements of curation impact ideation and collaboration? How do people use them?
2. How does information composition as a medium of assemblage impact ideation and collaboration? How do users individually and jointly assemble the rich bookmarks? How does this change across the spectrum of levels of consensus in collaboration, from when it is easily arrived at, to when it is never achieved?
3. How does consistency of representations for information impact ideation and collaboration?
4. How does consistency of spatial manipulation within and across workspaces impact ideation and collaboration?
5. How does the ability to hide and share information impact ideation and collaboration?

2.1 Curation Environment Overview

Our goals were to see the qualities of communication and collaboration in ideation tasks using embodied cross-surface curation environment. To achieve this, we built a *living-room lab*, a downscaled version of the living laboratory [30]. In the living room lab, we sought to situate the collaborative surface to facilitate access by participants, as well as their mutual human-human interactions. We designed the environment for use by intimate couples, so we wanted to make them comfortable and to promote their ability to express connection with each other. We created zones of interactivity and intimacy for participants, by positioning the collaborative surface amidst easily movable chairs on casters, and a couch (Figure 2.1). To support embodied cross-surface curation, we developed a tablet-based mobile IdeaMÂCHÉ application for users to collect Web information as rich bookmarks on their personal surfaces. On the collaborative surface, we developed an Embodied IdeaMÂCHÉ application for users to arrange rich bookmarks spatially to curate in the medium of information composition. We created embodied cross-surface interaction techniques for users to exchange rich bookmarks across surfaces using portals.

To build a living-room lab, we renovated one room of our lab to simulate the feeling of an actual living room, like [31]. We replaced the office furniture with living room furniture (couch, end table) and decorations (area rugs, curtains, paintings). We also replaced bright and cold fluorescent lighting with subtle and warm spotlights to mimic lighting conditions of an actual living room. We anticipated that this naturalistic design of the study environment would contribute to how people engage in the task. The participants would feel more comfortable in a homey environment than in an ostensible lab space. As a result, we expected that they would better immerse themselves in the task.



Figure 2.1: The cross-surface curation environment in the living room lab.

2.1.1 *Zones of Intimacy and Interaction in the Living-room Lab*

In the design of the living-room lab, we created three zones of intimacy and interaction that afford different levels of physical intimacy and privacy, and so different qualities of collaboration: Collaborative Surface Zones, Flexible Configuration Zone, and Physical Intimacy Zone. All the zones afford seeing the collaborative workspace and using cross-surface portals to share information.

The design of the intimacy and interaction zones is the product of blending room and device components. To create the zones, we placed two movable chairs on casters directly in front of the collaborative surface, on a rug. The casters afford participants to easily move and rotate their chairs. We also placed a couch about 6 feet away from the collaborative surface. With this layout, the living-room lab contains three zones (Figure 2.2 and Figure 2.3).

The first zone is the *Collaborative Surface Zone*. It encloses the area around the

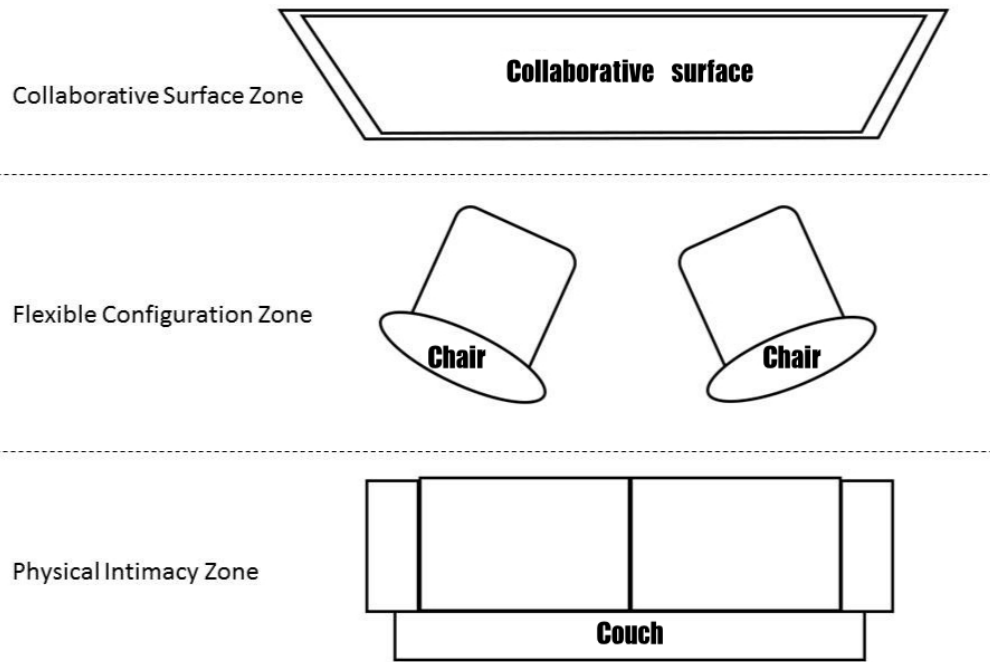


Figure 2.2: Zones of the cross-surface curation environment in the living room lab, defined in terms of the kinds of human-human and human-computer interaction that they afford, through their embodied characteristics. Each individual can freely position themselves in any zone. S/he can take her personal surface with her to any position, or temporarily shift it to chair or the couch, where there is space.



Figure 2.3: Examples of participants residing in different zones. Top left: Participants interacting with the information composition in the Collaborative Surface Zone. Top right: Participants using their tablets in the Flexible Configuration Zone. Bottom left: Participants using their tablets in the Physical Intimacy Zone.

collaborative where participants can directly touch the collaborative surface. This zone affords connecting devices, initiating cross-surface portals, and collaborative design using information composition.

The second zone is the *Flexible Configuration Zone*. It encloses the area between the couch and the collaborative surface. Each participant can sit on a chair or stand. Participants can stay close to the collaborative surface to easily switch to the first zone to work on the collaborative surface. They can also stay away from the collaborative surface to focus on working on the personal surface. This zone affords working independently on tablets. In this zone, participants can establish and maintain privacy in relationship to their partners. They can turn the chair away to hide the tablets using their bodies. When participants move close to each other, the zone also affords looking over shoulders and physical contact.

The third zone is the *Physical Intimacy Zone*. It encompasses the couch. Different from the chairs, the couch is a static surface on which participants can sit together and even recline. It provides intimate space for participants, especially for couples, to connect. On the couch, participants are able to directly face each other. It also affords overlooking. This zone most easily supports physical touch between users. It also affords privacy, though not as easily as the Flexible Configuration Zone.

2.1.2 Collaborative Surface Positioning: Drafting-Table Tilt

Our collaborative surface is a 55" HDTV flat-screen display, enhanced with Zero-Touch sensing to provide multi-touch interaction. We put the collaborative surface on an adjustable stand so that we could position the collaborative display to facilitate being seen and manipulated by participants. We experimented with different screen orientations for the collaborative surface. When the surface is horizontally placed, it serves as an interactive tabletop. An advantage of the horizontal tabletop

configuration would be that people can site around it, on all sides. Among disadvantages are the orientation problem, as material right side up for some would be upside down for others. When the surface is vertically oriented, as a wall display, it's vertical span is maximized. This makes reaching the whole span difficult.

Our goal was to position the surface to maximize its accessibility to participants. We settled on a 'drafting-table' configuration, with a 45 degree tilt. We positioned the surface vertically at a height compatible with the chairs and couch. This configuration affords maximal access to the vertical span of the surface. In this orientation, users can comfortably use the touchscreen in both sitting and standing positions, and touch their tablets to the peripheral NFC tags to initiate and move cross-surface portals.

2.1.3 *Personal Surfaces*

We used lightweight 7" tablets as personal surfaces for curation. It is easy to hold this type of tablet in one hand during a lengthy collaborative ideation task than larger and heavier tablets. Users can free up the other hand to interact with the collaborative surface or make hand gestures to communicate with other users. Tablets also afford *looking over*, in which one participants shows the screen to another users. This is handy for lightweight sharing and discussion.

It also means that users can always hold the tablet close to his body in a preferred spatial position. This is important because during the collaboration, users need to switch attention between the collaborative surface, the tablet, and other users. A user may change his stance, or body orientation to perform interaction on the social surface, to discuss with the collaborator or just to take a rest. It is handy to have the tablet readily available when it is needed and move it out of the way when the other targets need more attention.

These tablets work well with the collaborative surface in a synergy. The design of the embodied device connecting and rich bookmark sharing interactions considers the spatial relationships. It is intuitive to connect the devices by physically touching them. To share a rich bookmark, a user flicks the rich bookmark across table screen towards the top of the tablet screen, and towards the collaborative surface in front of him. After sharing, the rich bookmark slides on the collaborative surface from the edge. The user can continue other interactions with the rich bookmark on the collaborative surface without interruption. The information in the rich bookmark form moves on and across the devices in a spatial context. They move and appear in an expected way because of the spatial relationship.

2.2 Rich Bookmarks: Image Clippings with Metadata

We use *rich bookmarks* to represent ideas in the information-based ideation tasks. Users curate rich bookmarks from Web pages on tablets and share them to the collaborative surface to make information composition. Rich bookmarks are image clippings with metadata. An image clipping contains a representative image of the information on a Web page. Metadata contains semantic information of the Web page. For example, for a Web page of a piece of IKEA furniture, its metadata contains the product's name, price, specifications and reviews. User can select any image on a Web page to create an image clipping.

Rich bookmarks provide consistent representation of curated information across surfaces. They convey ideas of the curator. The metadata and the source Web page afford re-finding. Users can quickly get the essential information of a rich bookmark by viewing its metadata. Users can also explore the Web from a rich bookmark by navigating to its source Web page.

We developed interface on both tablets and the collaborative surface to support

visualizing metadata and navigating to source Web pages of rich bookmarks. On the tablet, users can view metadata during creating a rich bookmark, or from a rich bookmark stored in the collection (Figure 2.4). Users can navigate to the source Web page from a stored rich bookmark.

On the collaborative surface, users organize rich bookmarks spatially to form information composition [1, 6, 9]. They can view the metadata and the source Web page of a rich bookmark within the context of the information composition. We call the interface that shows the metadata and the Web page *In-context metadata and Web browser* (Figure 2.5). The in-context metadata and Web browser is a popup window that appears close to the rich bookmark in the information composition.

2.3 Cross-surface Portals

2.3.1 Creating Cross-surface Portals with NFC Tags

2.3.1.1 Peripheral NFC Tag Array

NFC tag stickers serve as an affordance for the user to connect his tablet to a space on the shared screen. An array of NFC tag stickers are placed on the bezel of the Zero-touch over the collaborative surface.

We also designed NFC cards to replace NFC tag stickers for the user study. The design of the NFC card cues the user to touch tablets with the NFC tag (Figure 2.7). The artwork indicates that it is intended to be used with a tablet to enable wireless transfer. It also implies the way the users hold the device to initiate the interaction. Future research can investigate the effectiveness of different artwork designs in helping the users to learn and perform the connecting interaction.

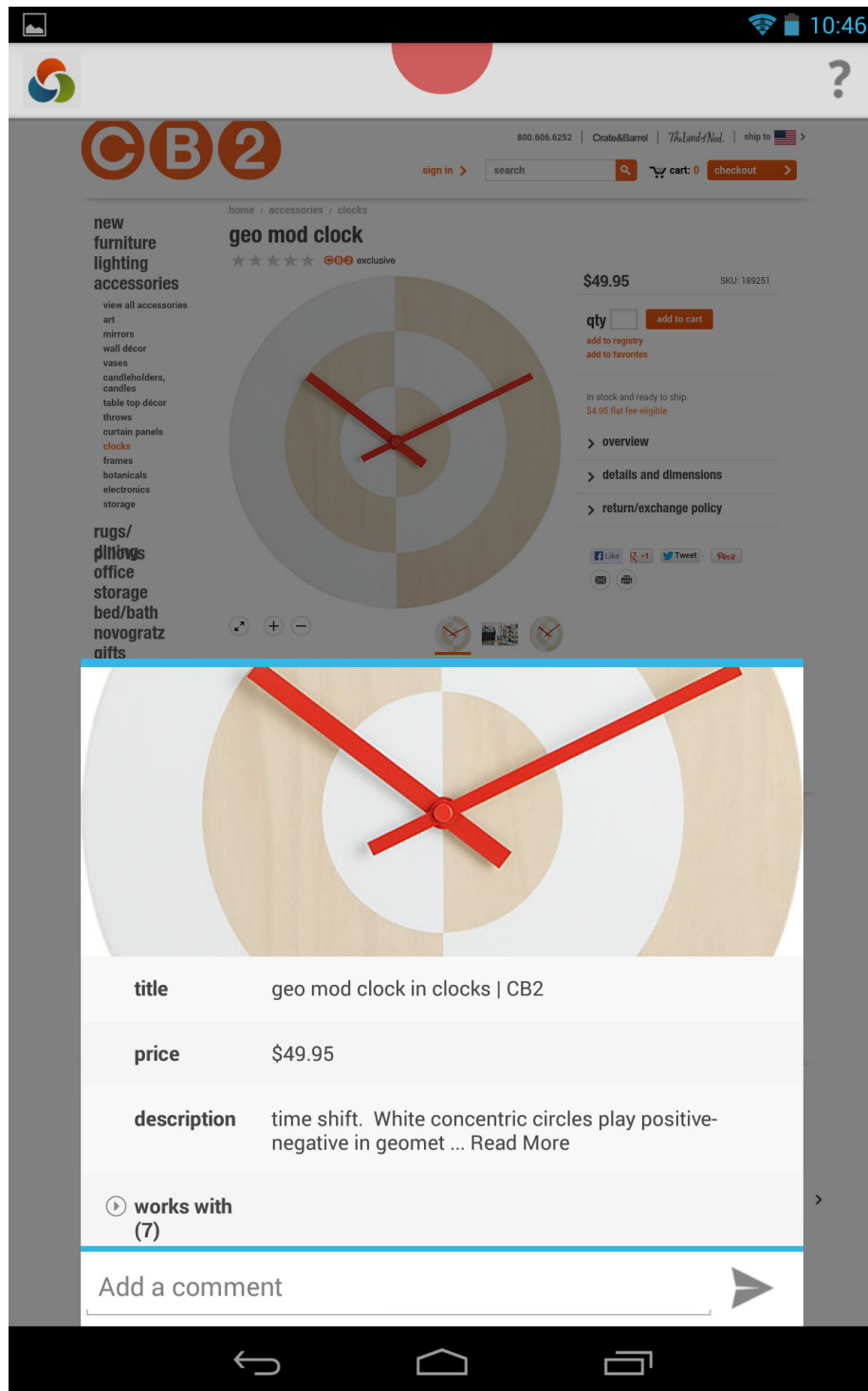


Figure 2.4: A screenshot showing a collected rich bookmark with the image and metadata. A user can drag the image towards the red portal on the top of the screen to share the rich bookmark to the collaborative surface.

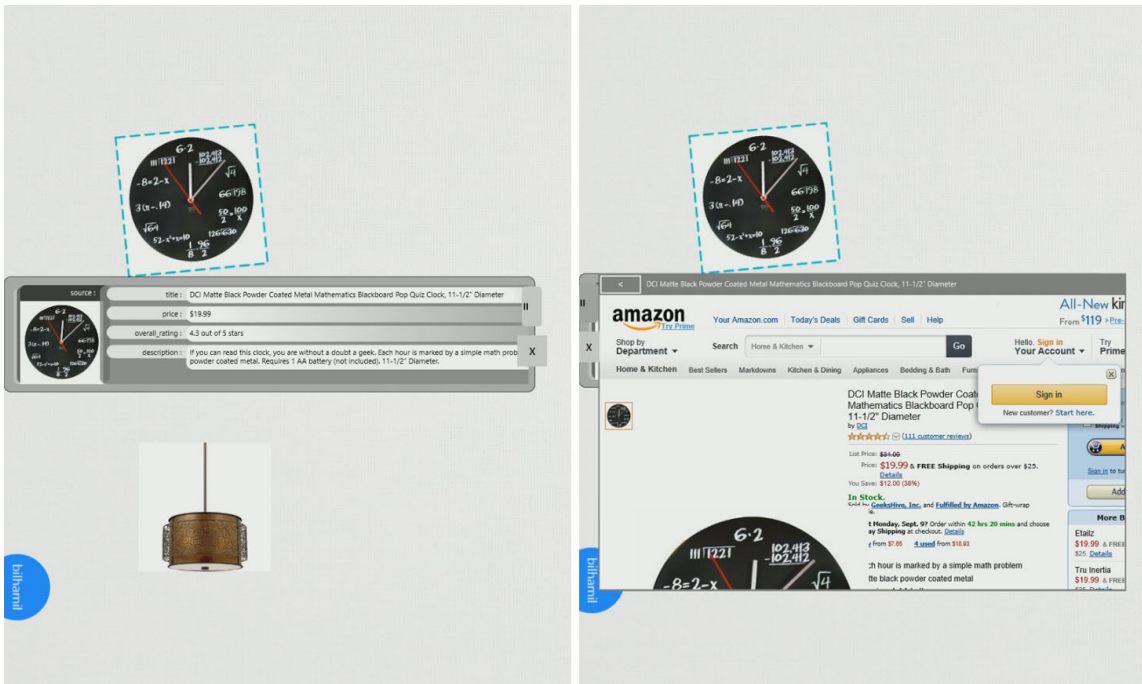


Figure 2.5: The in-context metadata browser (left) and the in-context Web browser (right) associated to the rich bookmark in the information composition.



Figure 2.6: Cross-surface interactive system with 55" flat-screen display, ZeroTouch sensor, NFC tags, and mobile devices.



Figure 2.7: Artwork designed for the business card-size NFC tag.

2.3.1.2 Active Portal Affordances

During the action of sharing physical things, movements of the shared objects are continuously visible. However, display surfaces are inherently disconnected physically in the multi-display cross-surface sharing scenario. To give users visual feedback of the transferring, we design portals as digital affordances for the cross-surface interaction. These portals are half circle close to the edge of each display. To create cross-surface portals, users touch a tablet on one of the NFC tags. Once a user touches a tablet on one of the NFC tags, a pair of cross-surface portals with the same color are created on both the tablet and the collaborative surface. The portal on the tablet appears as a half circle on the top edge of the tablet screen. The portal on the collaborative surface contains the user's name. It appears close to the NFC tag the user touches. At the same time the portals are created, the tablet plays a tune as audio feedback of the connection. The visual appearance of the portals and the connection tune together indicate that the connection is made. Users can break the connection between the tablet and the collaborative surface by shaking the tablet. To provide feedback of the disconnection, the portal on the tablet disappears.

2.3.2 *Transferring Rich Bookmarks through Active Portals*

Hands are our most familiar tools. Displays with touch-capabilities enable us to directly control the digital objects. Although the digital objects on the flat display is composed of pixels, making them inherently different than the physical objects we use, we designed embodied gesture for transferring information across devices that is perceptually familiar to how we exchange physical objects. Spatial relationship plays an important role in our interaction with objects and other people in the physical world. In the digital space, we considered the spatial relationship between the surfaces and users in our embodied cross-surface interaction design.

We created a *sharing gesture* for users to share rich bookmarks from tablets to the collaborative surface. Users can share one or more rich bookmarks to the collaborative surface by selecting and dragging them to the portal on the top of the screen (Figure 2.8). The size of the portal increases when rich bookmarks are dragged closer by. Once the user’s fingertip reaches the portal, an animation shows the rich bookmarks sliding to the edge of the screen, visualizing the transfer.

When we share personal things to others by hand, we move our arms and hands that hold the shared objects away from our body to reach the others. A user shares rich bookmarks across displays using cross-surface interaction by dragging them through the top of his mobile device, which is usually away from his body, and facing the collaborative surface. This interaction gives the user a sense of ‘send-away’. When a user drags an item to the portal of the mobile device, it slides out towards the top edge of the mobile display, and slides in from the position of the corresponding portal on the collaborative surface, providing visual feedback of continuous movement. When we take items from another person or from a public space, we grab them by hands and move them close to our body. In cross-surface scenario,

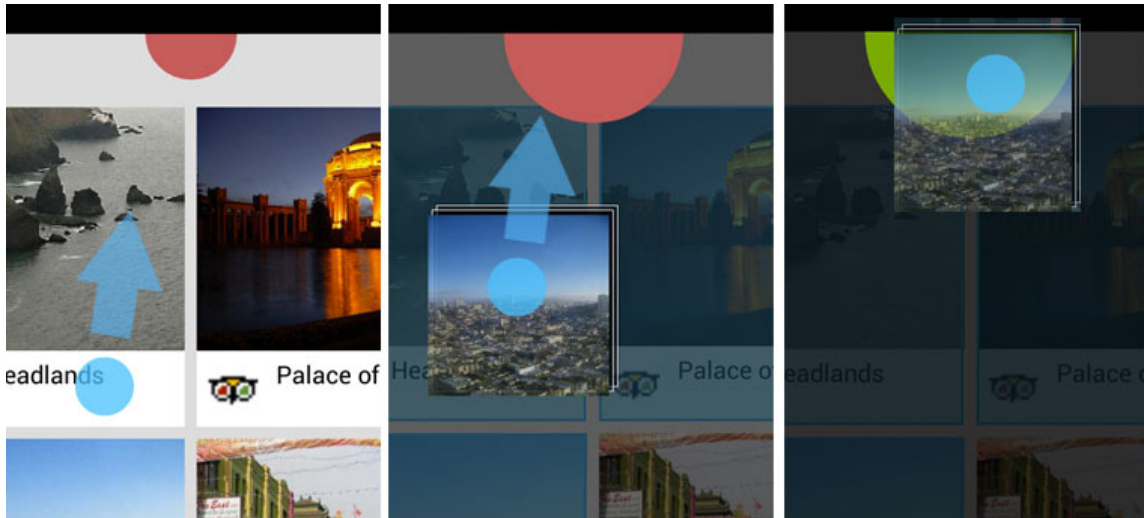


Figure 2.8: Gesture of sharing rich bookmarks to the collaborative surface through the portal on the tablet.

a user drags them towards the portal on the collaborative surface that is close to his body, giving a sense of ‘bring-close’.

The conventional ways of transferring digital information across devices, such as sending email, or instant message, is usually a binary operation. When a user hit a button to issue the ‘send’ command, the information is sent. The user cannot take it back. In the physical world, when we want to share things to others, we extend our arms until they reach the target. During this period, if we want to stop the sharing, we stop the movement of our arms, and take them back. The embodied cross-surface interaction mimics this process in the digital form. When a user drags a digital object towards the portal to share, she can cancel the sharing process anytime by lifting her finger from the object before the object reaches the portal. When a user shares rich bookmarks from the tablet, they slide onto the screen from the location of her portal (Figure 2.9). They stay close to the user’s portal when the animation stops, awaiting further interaction.



Figure 2.9: Shared rich bookmarks slide onto the collaborative surface and stay close to the portal.

2.3.3 Implementation

We put 6 NFC tags on the bezel area along each longer side of the ZeroTouch sensor, and 3 tags on each shorter side. The distance between tags is ~ 8 ". We placed tags outside of the display area, extending the display without taking up display space. We initially used round tags but later switched to business card sized tags. Readers may refer to Appendix B for more detail on the physical description and the design consideration for the NFC tags.

To track mobile devices' positions with the NFC tags requires sufficient linear density. At current setup, each user can reach 3 tags from any location around the television. When interacting with the collaborative surface, users are likely to maintain mutual distance [37]. A tag is an entry point of the collaborative surface, and it anchors a user's personal territory. Sufficient distance between tags also prevents a mobile device from detecting multiple tags at once. Spacing the tags

as tangible affordances simplifies the social and the technological.

We set up a WebSocket OODSS server application on the desktop computer that also powers the collaborative surface (Figure 2.10). It sends messages between the apps and the server with the OODSS (Object-Oriented Distributed Semantic Services) framework (See more detail of the WebSocket OODSS server in Appendix C). OODSS supports cross-platform communication by de/serialize XML messages using S.IM.PL, a cross-language type system [38]. The server listens to incoming connections from both localhost and an ad hoc Wi-Fi network hosted by the desktop computer. The server's IP address and port number along with the SSID and password of the Wi-Fi network are stored in NDEF (NFC Data Exchange Format) messages on the NFC tags. In order to track the users' positions around the collaborative surface, we also program the NFC tags according to their relative positions around the collaborative surface. Appendix B lists the data structure of the NDEF messages.

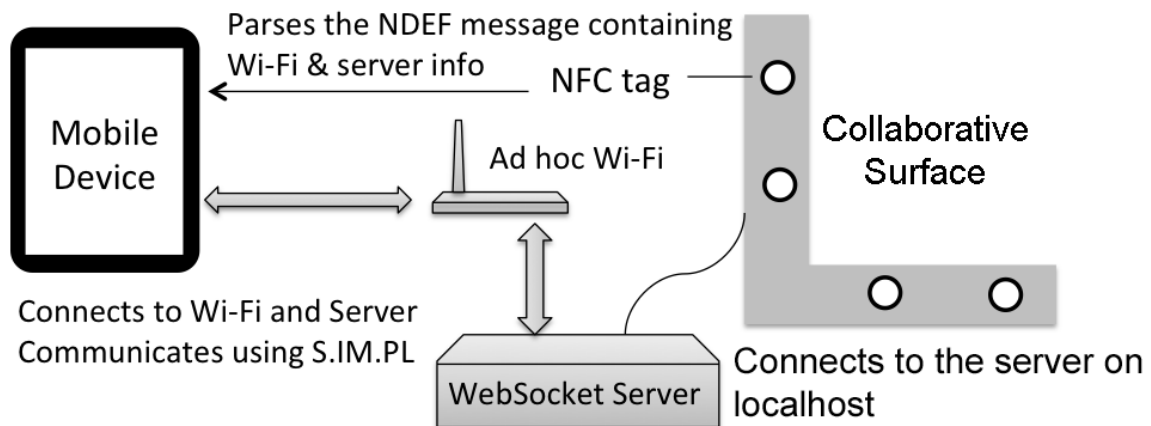


Figure 2.10: Communication between a mobile device and the collaborative surface through Ad hoc Wi-Fi connection. The mobile device initiates the connection to the WebSocket Server using information stored on NFC tags.

The tablet is configured to automatically start mobile IdeaMÂCHÉ application when an NFC tag is touched. The application detects and parses the information on the NFC tag. It connects to Wi-Fi network on which the WebSocket OODSS server is running using the SSID and the password obtained from the tag. It then initiates connection to the WebSocket server wirelessly using the IPv4 address and the port number obtained from the tag. Once connected to the server, mobile IdeaMÂCHÉ sends a TouchTagRequest to the WebSocket server. The server then sends a TouchTagUpdate to EmbodiedÂCHÉ. When EmbodiedÂCHÉ receives the TouchTagUpdate, it creates a portal on the collaborative surface, at the position based on the X-Axis and Y-Axis position received in the message. The portal affordance displays the username specified in the TouchTagUpdate message, with a color picked from a pre-defined color pool. Embodied IdeaMÂCHÉ then sends back the color in a ColorRequest to the WebSocket server, which subsequently sends a ColorUpdate to mobile IdeaMÂCHÉ. Once mobile IdeaMÂCHÉ receives the ColorUpdate, it displays a half circle on the top of the screen, providing visual feedback of successful connection. The half-circle affordance makes the cross-surface portal visible on the tablet. If a user has connected the tablet and the collaborative surface, touching another NFC tag at a new position moves the portal to the new position on Embodied IdeaMÂCHÉ.

Mobile IdeaMÂCHÉ registers to the accelerometer sensor of the device, and listens to the shaking motion. Once it detects a shaking motion, it sends a LogoutRequest to the WebSocket Server, which then sends a LogoutUpdate to Embodied IdeaMÂCHÉ. Embodied IdeaMÂCHÉ removes the cross-surface portal for the user. The server then sends back a LogoutResponse to mobile IdeaMÂCHÉ to breaks the connection.

During rich bookmark sharing, the mobile client sends a ShareRequest that con-

tains the user's ID and metadata form of the shared rich bookmark to the WebSocket Server, which then sends a ShareUpdate containing the same information to the mobile IdeaMÂCHÉ application on the collaborative surface.

2.4 Personal Surface: Private Curation of Rich Bookmarks

Users curate rich bookmarks using mobile IdeaMÂCHÉ mobile application on tablets. A Tablet is an personal surface that allows users to forage information from the Web independently. Mobile IdeaMÂCHÉ contains several components: 1) a component that creates rich bookmarks from a browser; 2) a personal collection that stores the collected rich bookmarks; and 3) a cross-surface mobile client that creates portals and exchanges rich bookmarks with the Embodied IdeaMÂCHÉ application on the collaborative surface. We describe the first two components in this section. The last component is described in the previous section.

2.4.1 *Creating and Storing Information as Rich Bookmarks*

On the tablet, a user browses the Web using the Google Chrome browser. When he finds interesting information, he can create an image clipping from the Web page by using the standard share action in Android to invoke the mobile IdeaMÂCHÉ mobile application (Figure 2.11).

The rich bookmark is then shown in mobile IdeaMÂCHÉ (Figure 2.4). The metadata browser shows the metadata of the page in an expandable list. Users can scroll and expand the list to see its nested fields. The application shows the image for the clipping above the metadata browser. If users are not satisfied with the image, they can dismiss the image by dragging it down. Then they can select any image on the Web page for the image clipping by touching and holding the image. Users can add annotation to comment the image clipping. The annotation is stored in the rich bookmark. Users can save the created rich bookmark to their personal

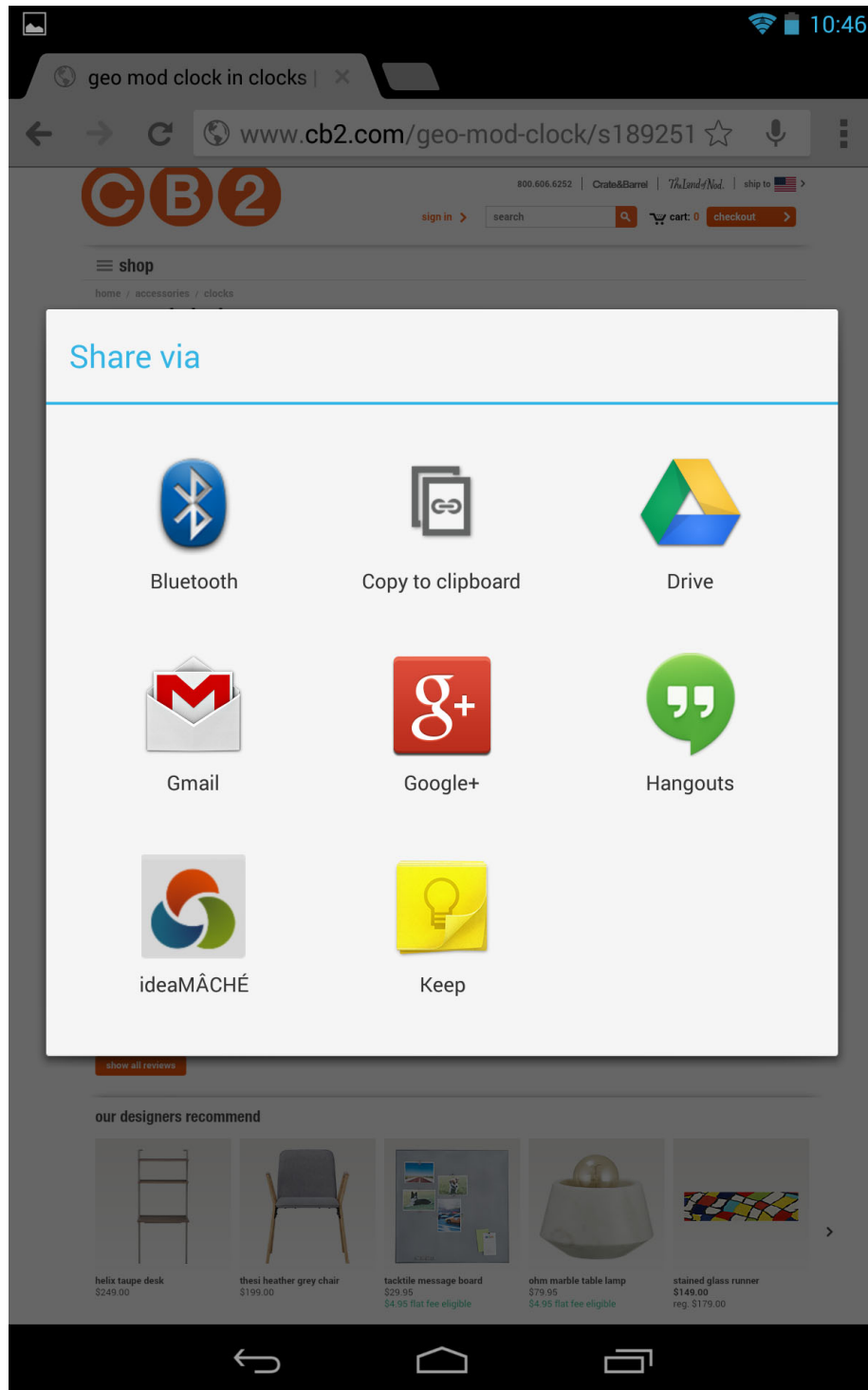


Figure 2.11: Invoking the mobile IdeaMÂCHÉ application through Chrome browser to create rich bookmark.

rich bookmark collections. Users can also directly share the rich bookmarks to the collaborative surface at this time. Shared rich bookmarks are saved to the collection automatically.

2.4.2 Private Rich Bookmarks Collection

When a user shares or saves a rich bookmark, the rich bookmark is stored in the user's personal collection (Figure 2.12). Saved rich bookmarks are organized in pages of cards. Each card shows a rich bookmark's image, title, and favicon of the source Web page. Swiping left or right turns to previous or next page of the collection. Pinching to zoom on an image brings up a view that shows the larger image and the metadata. Touching and holding a rich bookmark in the collection shows a context menu that allow users to navigate to the original Web page or delete the rich bookmark from the collection.

2.4.3 Implementation

In the initial design, we implemented a basic Web browser based on `WebView` class so that users can browse the Web inside our application. It has basic functions of a Web browser such as navigation, address bar, and search. Using a custom Web browser has the benefit that we can have a coherent browsing, collecting, and sharing experience. However, there are several drawbacks for this method. First, the performance of the `WebView` class is a lot slower than the native Web browser on Android such as the Chrome browser, especially for Web pages in which javascript is heavily used. In addition, to achieve functions such as auto-complete, history, bookmarks, and tabs of a native Web browser requires work that is out of the scope of this study. Therefore, we later switched to use the native Chrome browser.

Our application listens the URL sharing event of the Chrome browser. Once the mobile IdeaMÂCHÉ application is invoked by the sharing event, it sends a request



Figure 2.12: The screenshot showing a personal collection containing multiple rich bookmarks. A user can drag one or more images towards the red portal on the top of the screen to share to the collaborative surface.

to obtain metadata of the Web page from the BigSemantics service (Appendix A). The mobile IdeaMÂCHÉ application then loads the Web page as a background, and show the mobile metadata browser when the metadata is returned from the BigSemantics service (Figure 2.4). More explanation of how BigSemantics Service extracts metadata from Web page is in Appendix A.

Meta-metadata defines the rules of extracting metadata from a source Web page (See Appendix A for more explanation of meta-metadata). The meta-metadata for the Website specifies an image for the image clipping, the application displays the image based on the URL in the image clipping. The data structure of the collection is also defined in meta-metadata. It is of ‘collection’ type with ‘rich_bookmark’ as its child type. When the collection changes (i.e. the rich bookmarks are added, deleted, or modified), the whole collection is serialized using S.IM.PL as an XML file and stored on the storage of the tablet. When the mobile application restarts, it deserializes the stored XML file to load the stored rich bookmarks into the collection.

2.5 Collaborative Curation through Embodied Information Composition

Users perform collaborative curation through embodied information composition using Embodied IdeaMÂCHÉ. Embodied IdeaMÂCHÉ is a curation tool for assembling rich bookmarks via touch interface to support information based ideation tasks. Multiple users can work jointly on the information composition using Embodied IdeaMÂCHÉ on the collaborative surface. Users can move rich bookmarks spatially in the information composition by touching and dragging. They can pinch to zoom rich bookmarks, and use two fingers to rotate rich bookmarks. In addition, we provide interactions through the portals, and allow user to layer rich bookmarks.

Table 2.1: A list of menu items of the portal on the collaborative surface and their functions.

Menu Item	Function
Delete	Removes the rich bookmark from the composition.
Share	Transfers the rich bookmark to the tablet associated with the portal to view the source page and store the rich bookmark on the tablet.
Search	Sends a search query to the tablet associated with the portal to do a Web search.

2.5.1 Functions on the Portal Menu

We implemented the following functions in the menu of the portal on the collaborative surface listed in Table 2.1.

Dragging a rich bookmark to a portal on the collaborative surface activates a menu of circled commands in light gray color (Figure 2.13). Once the menu is activated, the rich bookmark becomes semi-transparent, so that the user can see the menu items underneath. The portal also turns to green.

There are two different modes to trigger a menu item in a portal menu. In the novice mode, after the menu is activated, the user can lift her finger, and then tap one of the menu items to trigger the corresponding function. In the expert mode, after the menu is activated, the user can keep sliding her finger on the screen across a menu item. The rich bookmark sticks to the fingertip throughout the interaction, until the fingertip leaves the screen. The fingertip has to pass a majority length across a menu item so that the system can recognize it as an intentional action. Moving the fingertip out of the portal region deactivates the menu.

We provided both visual and audio feedback to indicate that a menu item is triggered. When a menu item is triggered, the menu item changing its color from gray to green, and the Embodied IdeaMÂCHÉ plays a tune. The tune is distinctive

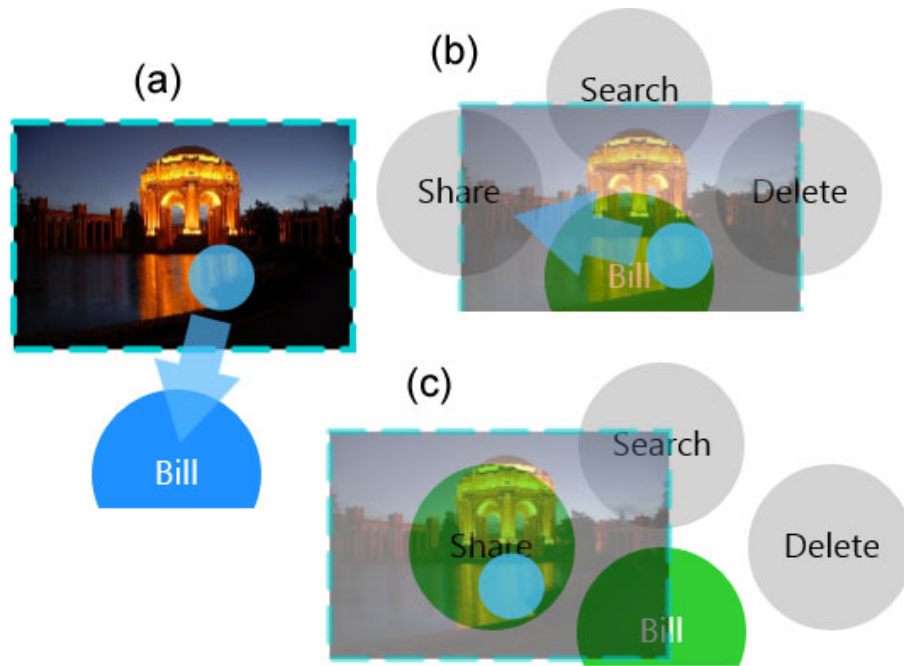


Figure 2.13: Gesture of activating radial menu and sharing rich bookmarks to the tablet through the portal on the collaborative surface.

for each menu item.

2.5.2 *Adjusting Layers of Rich Bookmarks*

Layering gives three-dimensional perception of a group of objects in two-dimensional space. It is useful to put a rich bookmark over other rich bookmarks to express spatial relationships between them. Users can adjust the layer of rich bookmarks using a ‘layer slider’. Holding a rich bookmark reveals the layer slider (Figure 2.14). Moving the fingertip up to the ‘front’ moves the rich bookmark above other rich bookmarks. Moving the fingertip down to the ‘back’ moves the rich bookmark below other rich bookmarks, which is convenient to make one rich bookmark the background of others.

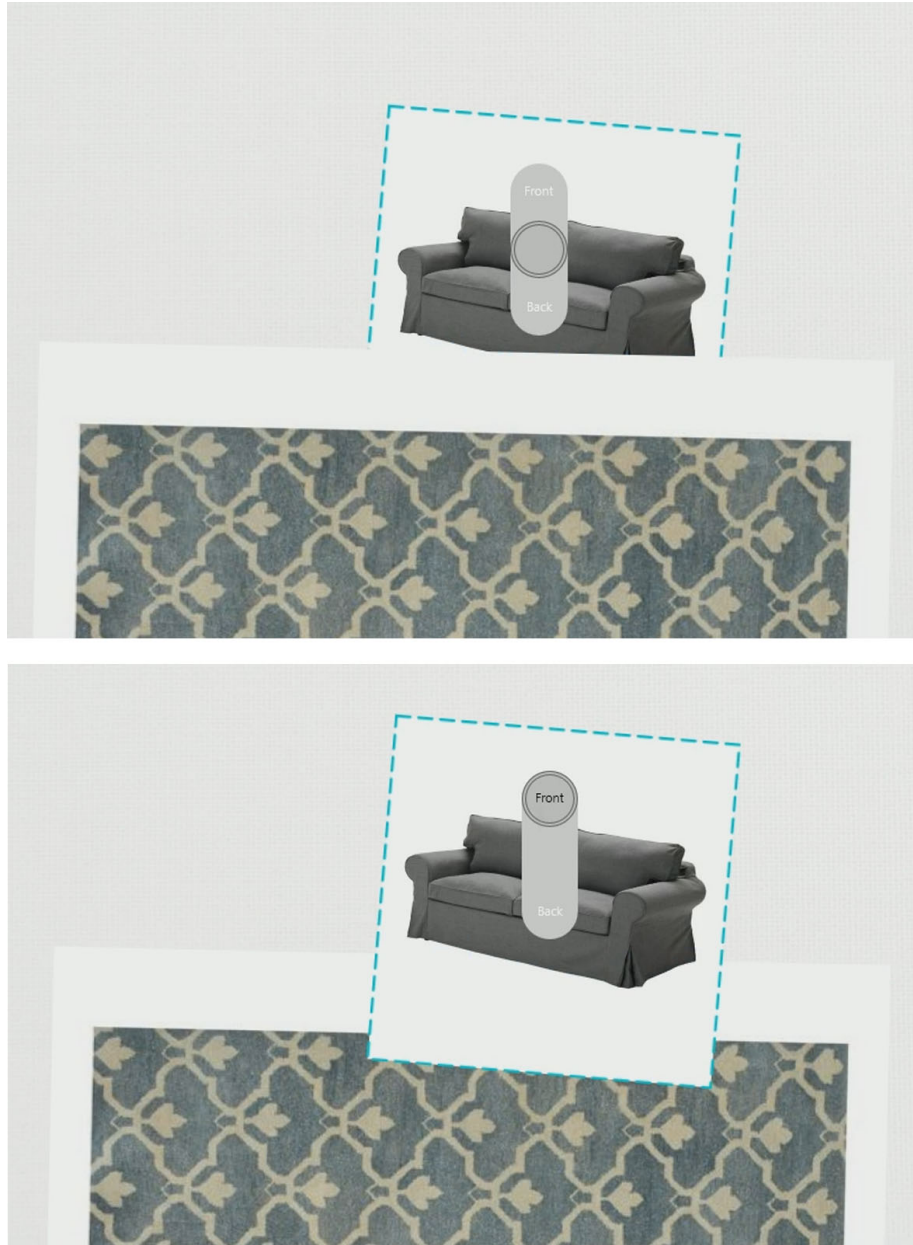


Figure 2.14: Using the layer slider to adjust the layer ordering of the rich bookmarks in the composition.

2.5.3 *In-context Metadata and Web Browser*

Double tapping a rich bookmark in the information composition reveals the in-context metadata and Web browser and places it on the top or below of the rich bookmark depending on the size of the browser and the empty space of the composition. When the in-context metadata and Web browser window is shown for the first time, it displays the metadata of the rich bookmark. To switch from showing the metadata to the Web page, users can drag a slider from the right edge to the left. Dragging it towards the opposite direction hides the Web page, and reveals the metadata again. Tapping the close button closes the in-context metadata and Web browser window. When the users double-taps the rich bookmark again, it reveals the browser window again, showing either the metadata or the Web page depending on which was shown before it was closed.

2.5.4 *Implementation*

Embodied IdeaMÂCHÉ starts by loading the type system scope for cross-surface OODSS messages, and connecting to the cross-surface WebSocket OODSS server by sending a SocialConnectRequest.

When the ‘Share’ menu item is triggered, Embodied IdeaMÂCHÉ sends a ShareToMobileRequest message containing the rich bookmark and the user information associated to the portal to the WebSocket OODSS server. The server then sends a ShareToMobileUpdate message to the tablet associated with the portal. When mobile IdeaMÂCHÉ receives the message, it shows the source Web page of the rich bookmark in the Chrome browser, and adds the rich bookmark to the personal rich bookmark collection.

The search function is similar to the share function. Instead of sending rich bookmark, Embodied IdeaMÂCHÉ sends to the WebSocket OODSS server a SearchRe-

quest, which contains the search query, which is the title of the rich bookmark. The server then sends a SearchUpdate to the tablet associated with the portal. When mobile IdeaMÂCHÉ receives the message, it navigates to a Google search page showing the search result based on the search query.

2.6 Design Considerations

In this section, we discuss common design issues for systems supporting co-located collaboration and our considerations and approaches to handle these issues in our collaborative curation environment.

2.6.1 Awareness

Awareness specifies how well the interactive system presents or makes visible the ongoing actions and intentions. Awareness is often manifested in subtle ways in multi-user interface for collaboration. Implicit mechanisms of awareness include: making verbal commentaries on actions, or physical movements to avoid collisions or demonstrate possessions [39, 40]. Multi-user touch surfaces enhance awareness compared to surfaces with other input devices [39], and attract and engage people standing around to interact with them [41]. However, high degree of simultaneous actions by multiple users may cause information and cognitive overload [42]. Design for awareness in a collaboration needs to address three questions: *who*, *what* are other collaborators doing, and *where* [43].

2.6.1.1 Who

Awareness of ‘who’ considers whether someone else is participating, who is participating, and who is doing a specific action. Our curation environment provides a multi-touch display as a shared collaborative surface that allows more than one users to create information composition collaboratively. Users are aware of their col-

laborators' presence and interactions explicitly since they can only interact (move, rotate, delete) with rich bookmarks on the shared surface through touch-based gestures. When a user's mobile device is connected to the collaborative surface, a portal that identifying the user with color and name appear close to the user, indicating the presence of the user. The portal moves to new positions when a user moves around a table. Using user-identifying portal provides possibilities for customization of appearance and function of the portal for different users [44].

2.6.1.2 What

Awareness of 'what' considers what other participants are doing, what goal of the action is, and what objects other participants are working on. Our curation environment supports information-based ideation, which contains collective information seeking. Collective information seeking is a form of collaboration grounded in awareness of the work environment. Its goal is changing during the process[45]. In our environment, users collect and share rich bookmarks via their personal mobile devices. Multiple users can work in parallel in exploring and collecting information on their mobile devices without interfering with other users. Using this method, users are still aware of what their collaborators are working on. They can lean towards their partners to peek at their tablet screens. A user can easily monitor the rich bookmarks shared by his collaborators, and manipulate these rich bookmarks after they are shared to the collaborative surface.

2.6.1.3 Where

Awareness of 'where' considers the location other participants are, where they are looking, where they can see, and where they can reach. To manipulate a rich bookmark on the collaborative surface in our curation environment environment, a user directly touches it. On the collaborative surface, users can reach rich bookmarks

that are close to themselves. They have limited reach to move a rich bookmark to a place or bring a distant one close to them. To allow users to manipulate out-of-reach rich bookmarks requires a relative input that replaces the physical embodiment with the virtual embodiment [46]. We choose physical over virtual embodiment. Users have to either move around the collaborative surface to reach object, panning the composition, or explicitly communicate with other people to hand the rich bookmarks over, which increases mutual awareness in the collaboration.

2.6.2 Coordination

Groupware with touch support inevitably introduces conflicts among users [47]. These conflicts occur in *global* scale and *element* scale [48], requiring coordination among participants to resolve. Global conflicts are those that affect the application as a whole. Element conflicts involve access or change a single object as a whole.

Pinelle *et al.* [49] developed mixed initiative, embodied element coordination policies. A user's control level of an element decreases with the increase of the distance between the element and the user's personal territory. In another type of policy, a user's control level increases when the user apply more pressure / force when he interacts with the object. Marshal *et al.* [17] implemented a voting system in their application. All the users have to agree on a change by selecting 'yes' before it can proceed. However, policies such as sequential interaction, voting, or predetermined territories hinder the fluent and dense touch interactions [39]. Sometimes, a more lightweight approach is preferred. Instead of relying on enforcing the coordination policies, system may encourage explicit negotiation among users to resolve conflicts [47].

Our goal for designing coordination policies for our system is to use as little restriction as possible in order to preserve the task continuity. In our application on

the collaborative surface, we identified several potential coordination issues in global and element scale.

Global scale coordination include:

1) Making connection between a mobile device and shared surface at an occupied location

To avoid conflicts between two users occupying the same position, we rely on the common ‘social protocol’ that one should not invade other’s personal space.

2) Panning the workspace on the collaborative surface

The workspace on the collaborative surface is a pannable composition space. Any direct touch on the composition space to one direction will move the composition space. Since there is no identifying capabilities to distinguish touches from different users, conflicts will occur if more than one participant want to move the composition space towards different directions. It is very easy to notice when this situation happens. Participants can stop immediately and negotiate, or take turns to move the composition space.

Element scale coordination include:

1) Ownership

In our system, users share collected rich bookmarks from their mobile devices to the collaborative surface. We apply loose concept of ownership on a rich bookmarks. We do not prevent a user from deleting a rich bookmark shared by other participants in the shared information composition. It only removes rich bookmark from the shared composition. Such rich bookmarks still exist in personal collections on the mobile devices where they were originally curated.

2) Scaling / translating / rotating rich bookmarks

To encourage evolvment, we do not restrict these interactions on the rich bookmarks based on ownership. Size, position, and orientation are important expressive

visual properties of a rich bookmark in a composition. We want users to solve conflicts on these properties through verbal negotiation and discussion. It also provides opportunities for two users to collaboratively manipulate one rich bookmark.

3) Activating / deactivating metadata browser / web browser.

We designed the metadata browser and the web browser to appear ‘in-context’, so that users do not need to leave the composition to view the information associated with the rich bookmarks. However, one drawback of this design is that the browser view may cover other rich bookmarks. When a user is browsing metadata or a web page, the rich bookmarks underneath are not available for other people to use.

2.6.3 Territoriality

Users naturally partition the workspace in an interactive surface into *territories* during collaboration [50]. Scott *et al.* [50, 51, 52] divided the display space of a shared surface into three type of territories: *personal*, *group*, and *storage*.

The *personal* territory provides each user a dedicated space to work independently. It is where a user usually editing the objects. Users consider this personal territory as a ‘safe’ place to explore alternative ideas. It also allows users to ‘parallelize’ the task without interfering with each other.

In our system, we externalize the personal territory to the mobile device. Users perform most of the information collecting tasks on the mobile device, saving space on the shared surface for creating composition. Since people often change their personal spaces during tasks [16], the complexity of workspace expanding, contracting, or shifting to different locations on the table are simplified. The personal territory / space always follows the user, and no information is revealed to the public until user shares it. The tabletop application does not need to include everything that users can do, since user can perform various tasks on their mobile devices. We can easily

expand the functions of the system. Although there are no explicit personal territories on the shared surface, each user still can claim their presence in the collaboration with the portals.

The *group* territory is where the main task activities occur. Since we externalize the personal territory, users can use the whole display space for making information compositions.

The *storage* territory serves as areas for task resources. Users often use it to organize items. When needed, users can move items from the storage territory to other territories. In our curation environment, the storage territories are loosely located. The mobile application provides a curation tool in which each user collects rich bookmarks of interest. From the collection, users can easily transfer them to the shared surface using embodied cross-surface interaction. Shared rich bookmarks first appear in a stack close to the user’s portal on the surface when shared. The stack is a transitional storage territory. Users can also freely use open space on the tabletop as temporary storage space to put rich bookmarks before using or deleting them.

2.6.4 Equality

When using conventional single display groupware, with a single mouse and keyboard, one person and only one usually takes control. It relegates others to observing roles. Multi-touch input encourages more discussion during collaboration [42] compared to single-touch, but not necessarily increase equality of participation. Marshall *et al.* [53] found that compared to mouse input, multi-touch interface increases physical interaction equity but not the verbal equality. Quiet people remain quiet regardless of the interaction type. Rogers *et al.* [54] found that tangible interfaces (the physical-digital condition) provide more verbal equality than the tabletop

condition, while the latter provides higher physical equality. With a tangible interface, participants who speak less tend to contribute more physical action, indicating that by providing multiple input modalities, participants who are normally unable to verbally contribute are able to contribute in other forms. This promotes greater overall participation. In CoSearch [55], participants felt more ignored using mobile device with a shared screen, compared to using a single shared screen. This was likely because in their system, the shared items were queued. Only one person could take control of the shared screen at a time. In our application, we provide multiple concurrent entry points for participants to contribute to the collaboration. They can collect rich bookmarks on their personal mobile devices without interference by others. It enables them to explore their own ideas independently and in parallel. Multi-touch interaction on the collaborative surface does not have the problem that only one user at a time can interact and thus dominate interactions.

Spatial organization also suggests the right each participant has or the role he takes in the collaboration, affecting the equality of participation. In a collaboration with only one set of input devices to control the collaborative surface (like a computer with keyboard and mouse), one person (the driver) usually takes the control of the input and dominates the display, making other participants (the observers) sitting behind the driver feeling being ignored [55]. Because of this inequality caused by the physical constraints of the control devices, it is not easy to initiate face-to-face communication. In order to do so, the driver has to give up the attention on the collaborative surface. Otherwise, the other participants have to interrupt and take driver's attention away. A large multi-touch enabled collaborative surface eliminates the physical constraints, providing participants with equal opportunities of contributing.

3. RELATED WORK

Our work belongs to an extensive scope of literature in interaction design, human centered computing, computer supported cooperative work, and computer supported creative activity. In this chapter, we explore the related work from four aspects that coherently forms the study space. In this study, we developed embodied cross-surface interaction technique to facilitate communication and collaboration by sharing rich bookmarks across mobile devices and a shared collaborative surface. We start by surveying various interaction techniques to associate multiple devices. Next, we investigate various cross-surface interaction techniques that move information objects across displays and devices. We built technology to support a group of people to collaboratively perform everyday creative activities, in the form of information-based ideation. In the third section, we go from the technique to a bigger picture, to see how interactive surface and synergetic integration of multiple devices integrated in co-located collaborative tasks in previous studies. Then, We discuss how to evaluate tools that support information-based ideation.

3.1 Devices Association Techniques

Designing cross-surface information exchange techniques requires creating *bridges* that connect various *seams* among devices [56]. In this section, we present several existing device association techniques. The interaction designed for cross-surface information exchange relies heavily on the type of the device association techniques. We will discuss these interactions in detail in the next section. We divide the devices association techniques in several categories: 1) key based techniques; 2) accelerometer sensor based techniques; 3) computer vision based techniques; 4) RFID based techniques.

Key based association techniques are useful when pairing a mobile device to a large display. The large display presents a key for the user to input on the mobile device. A key can take various forms, such as alphanumeric string that a user can enter with the keyboard. A key can also be a sequence of motions that requires the user to perform with the mobile device [57]. Visual patterns such as a QR code can serve as the key [58]. Devices equipped with cameras can capture and decode the connection information stored in such keys.

Another group of association techniques use accelerometer sensor data from the mobile devices. Ramos *et al.* [59] and Hinckley *et al.* [60] used bumping as synchronous gesture to pair two tablets through a synchronous server. When two tablets bump against each other, each tablet records the movement data detected by the on-board accelerometer sensors, and sends the information to the server. The server analyzes the data and finds the matching patterns to connect the two bumped devices. In *PhoneTouch* [61], Schmidt *et al.* allowed users to exchange information between a mobile phone and an interactive tabletop. When a mobile phone touches the surface of the tabletop, it records the timing of the peak of the accelerometer data, and sends it to the server. The server compares this information with the timing of touches on the tabletop to distinguish the touches by the phones.

Both techniques require the mobile devices to have prior knowledge of a synchronous server. Thus, they are not suitable for situations when this information is not available outside of a lab, especially in the public environment. In addition, these techniques rely heavily on the patterns and the timing of the accelerometer data. Many concurrent users can introduce noise that potentially reduces its accuracy.

One category of techniques makes use of video and/or depth cameras to facilitate cross-device handshaking and information exchange by tracking the users or

their mobile devices' positions. 'BlueTable' uses projection-vision system to initialize handshaking between a horizontal interactive surface and multiple mobile devices [62]. It provides a natural interaction for making connection by placing the mobile device on the interactive surface, and breaking the connection by removing the device. BlueTable connects to a Bluetooth enabled mobile device, and commands the device to blink its infrared port. If this device is placed on the table, the infrared camera will detect the blink instantly and synchronize its timing with the command in order to differentiate devices. Some factors limit the use of this technology. Using a mobile device as a token on the interactive surface sacrifices display space on the surface. The mobile device does not hold still when the surface is not level.

Marquardt *et al.* developed *GroupTogether* to use a pair of depth cameras with the help of multiple radio modules to triangulate the locations of users and their devices [28]. These complex techniques have their advantage of precise position tracking when used in a confined environment. However, their scalabilities to open environment and more users are not clear. These systems require advanced algorithms and computing resources to operate. In addition, the complexity of these systems may reduce their reliabilities due to the rigorous requirement of calibration and synchronization between sensors and the reliabilities of individual sensors.

RFID (Radio-frequency identification) uses radio-frequency electromagnetic fields to transfer data wirelessly in order to identify tagged objects. Different RFID systems use various frequency bands that work on distances range from a few centimeters to 200 meters. NFC (Near field communication) is a set of standards based on RFID for mobile devices like smartphones. NFC technology allows a capable mobile device to read passive RFID tags by touching or bringing together within close proximity, usually a few centimeters. NFC tags are cheap and flexible. They fit different types of interactive surfaces, regardless of their touch-technology, form factor, shape, size,

orientation, or number of users. Physical tags embody the connection configuration procedures in the touching gesture. They contain natural affordances for the intended action since making connection is usually associated with touching. These techniques do not require mobile devices to have prior knowledge of the server, nor do they require pattern or vision-based synchronization. Pering *et al.* [63] developed *Elope* system to allow mobile devices equipped with RFID sensors to associate with tagged objects through a server. Tags on the objects contain information of the server. Programmed tags can achieve different intentions.

Sugimoto *et al.* [64] used RFID tags to track the locations of PDAs on a shared display. The display contains grids and each grid has an RFID tag. Touching the RFID tag with a PDA device shows the information of the associated grid on the PDA. Seewoonauth *et al.* developed Touch & Connect [65] technique using NFC to initialize a Bluetooth connection between a mobile device and a computer.

3.2 Cross-surface Information Exchange

Designs of the interaction techniques for cross-surface information exchange focused on seeking illusions of physical and/or visual continuity. For instance, Rekimoto *et al.* [66] used a digital pen to transfer information between computers by ‘picking it up’ from one display and ‘dropping’ it on another. The ‘Pick-and-drop’ interaction makes users feel that they are physically transferring digital objects. Hinckley *et al.* [60] used ‘stitching’ to transfer information across devices. This technique requires associating two devices first by ‘bumping’ them together. Moving one object towards the touched edges of two displays by a digital pen initiate the transfer. The transferred object appears on the locations of the second display that makes it appears that it is continuous on the two displays. Their technique is suitable for infrequent mobile-to-mobile information exchange between two users but is limited

in the situation when more people are involved in collaborative work.

In BlueTable, information ‘spills’ onto the screen close to the mobile device put on the screen [62]. PhoneTouch [61] allows users to exchange information between phone and tabletop by performing ‘pick-and-drop’ interactions using phones. The touch point footprint of the phone touch is smaller than finger touch. The camera beneath the touch screen detects phone touch and uses accelerometer sensor data to synchronize the devices. These seamless information exchange methods are advantageous in that the sender directly controls the location of transfer. However, physical contact of the mobile device with the interactive surface may interfere with ongoing tasks and other users. Information sharing has to occur on empty spaces on the screen. When the screen is full of information, it is hard to differentiate sharing and receiving. In addition, it can be cumbersome to perform when a large tablet is used.

Alternatively, *portal* embodies cross-surface information exchange without physical contact between devices [14, 28]. Wu and Balakrishnan’s ‘wormholes’ exchange objects between regions on a single tabletop [67]. The Portal extends the wormhow to exchange objects between multiple displays. Kerne *et al.* sent cards through cross-surface portals between smartphones and predefined locations on a tablet [14]. Once initiated, the cross-surface portals leveraged the spatial positions of the users and their devices. However, the assignment of players to positions at the start of the game was arbitrary. The present technique dynamically creates and relocates cross-surface portals, giving users clear visual feedback of their positions. Users interact with portals using touch gestures to transfer rich semantic information across devices.

With NFC initialized connection, previous implementation such as the Android beam [68] and [69] exchanged information through direct NDEF (NFC Data Ex-

change Format) messages between two NFC enabled devices. In Android Beam, users touch two devices together to initiate the information exchange. Data transfer can be delegate to connection with faster bandwidth such as Bluetooth for applications like photo exchange [65] or via third party service. However, there is no visible affordance to control the exchanged object.

3.3 Tools Supporting Co-located Collaboration

Stewart *et al.* [70] introduced *Single Display Groupware* (SDG) as a model for supporting co-located face-to-face collaboration. SDG typically contains a single display with multiple input devices for simultaneous use. They argued that the being able to work more effectively by working in parallel is one of the benefits of using SDG in the creative domain including brainstorming and other creative, expressive tasks. However, working in parallel may also be a disadvantage if there are conflicts in users' intentions. One user's decision could negatively affect others. Working in parallel with multiple input devices may reduce collaboration because users are able to work on their own tasks without communication with collaborators.

Various studies had used SDG on many different collaborative sensemaking tasks. Shen *et al.* [71] developed *Personal Digital Historian* (PDH) system for multiple users to share and build the digital group histories on an interactive tabletop. Users can explore, annotate, group and query photos, videos, and text documents in different layouts of these digital materials based on person, event, location, and time. Users can also rotation the hole interface and resize individual object. PDH facilitates conversation and storytelling among users. However, it used the digital materials collected prior to the tasks. Users could not actively add information to the system during the tasks.

Other use cases of SDG include: seating planning [39], learning [40] , and design-

ing [41]. Many studies investigated *collaborative search*, where multiple users work together to fulfill a shared information need [72]. For example, Morris *et al.* [73] developed *WeSearch* to support collaborative search and sensemaking on a tabletop touch display. Each participant takes one side of the display with her own browser window and software keyboard as input device. One unique feature is that users can make clips such as related keywords, web search results, images, and news article summaries from the web pages. Such features facilitate collaboration among users. Although the result of the study showed that clips did not directly support division of labor to increase the efficiency, they did help the sensemaking process and reduce the clutter. However, personal spaces on a single tabletop caused clutter issues and the software keyboards on the tabletop provided subpar text-entry experiences.

Other studies incorporate personal devices with the shared single display, extending the SDG model. Amershi *et al.* [55] developed *CoSearch* that allows users to conduct collaborative search using their mobile phones to control the shared-computer through Bluetooth connection. Users submit their own search requests from the mobile phones and the requests are queued on the shared-computer. The shared-computer transfers the results or the web page back to the mobile phones for personal use. *CoSearch* increases the efficiency of the collaborative search than using single shared-computer by enabling distributed control and division of labor.

With the advancement of the mobile technologies, smartphones and tablets become increasingly powerful. The users can perform more tasks on the personal devices. Seifert *et al.* [29] designed *MobiSurf* that enabled users to conduct web searching in a co-located collaboration way through integrated mobile devices and interactive surfaces. Users can switch freely between devices during the tasks since both mobile devices and shared surface support simple web browsing. They can also transfer the URLs of web pages between mobile devices and the shared surface

using PhoneTouch [61]. In the tasks of trip planning and gift shopping, MobiSurf enhanced sharing, communication and awareness between collaborators than using multiple laptops and sharing through instant messages.

Multiple personal devices connected to a shared surface have supported use cases other than collaborative search. Sugimoto *et al.* [64] developed *Caretta*, a system integrating a shared multiple input sensing board and PDA devices to support collaboration in urban planning tasks. Users can switch seamlessly between working on their own ideas on the personal spaces on PDAs and cooperating with others on the shared surface. In *Caretta*, the personal space can either mirror the shared space or show a portion of it. Providing a personal space for a user is beneficial since a user can experiment and simulate the result on her PDA before sharing it to the group without interfering her collaborators.

Wallace *et al.* [74] studied the co-located collaborative sensemaking process using different combinations of shared tabletop and tablet devices. In one condition, participants each had a tablet containing unique information that they could share to the tabletop to obtain best outcome through group discussion. In the sensemaking task, the participants individually explore and examine information on their tablets, compare shared information on the tabletop, arrange the information in the forms of tableaux in order to describe the result. Using shared tabletop with tablets significantly increases insights/depth of the discussion than using tablets alone. Users shared more information to the tabletop from the tablets than using the tabletop only.

We present a unique embodied cross-surface interaction technique between mobile devices and a collaborative surface that support group information-based ideation with multiple displays. Co-located users collect rich information on the mobile devices and share them to the collaborative surface. They also collaborate on the col-

laborative surface to manipulate the shared information to facilitate their ideation tasks.

3.4 Evaluating Information-based Ideation

We build out embodied cross-surface curation environment to support co-located collaborative information-based ideation. Information-based ideation demonstrates creativity from participants. *Divergent thinking* is essential to creativity in learning and problem solving [75]. Divergent thinking tasks look for many relevant answers to the questions instead of just one single answer. To achieve the goals of generating and developing quality results in information-based ideation tasks, one search for many possible ideas, requiring divergent, creative thinking.

To evaluate the information-based ideation, we used metrics developed from previous works. Cognitive psychologists measure creativity using *creative cognitive* approach, which study the aspects of the cognitive processes and structures that are relevant to the creativity [76]. Shah *et al.* [77] developed *ideation metrics* for measuring the ideation effectiveness in engineering design. They have four different metrics: *novelty*, measures how unique an idea among all the ideas; *variety* measures how wide the users explore the solution space in the ideation process; *quality* measures how feasible an idea is, and *quantity* measures the number of ideas generated.

Kerne *et al.* extended the ideation metrics from engineering design to evaluate curation tools' support of information-based ideation [1, 78]. In study tasks, each participant created a curation using clipping found objects from Web pages. The researchers evaluated performance of information-based ideation tasks by measuring the curation products using two kinds of information-based ideation metrics. *Elemental metrics* metrics of information-based ideation include *Fluency*, which measures the total number of ideas generated; *Flexibility / Variety*, which measures the

number of different ways of thinking and interpretation; and *Novelty*, which measures the uniqueness of the ideas.

In this research, we focused on how well our system enables users to work collaboratively on an information-based ideation task. We used Fluency and Flexibility metrics to evaluate each curation product generated by study participants. Kerne *et al.* computed Fluency of the curation $Fluency_M$ based on two types of media of the clippings found object: image and text. So $Fluency_M$ is a vector of two elements $Fluency_{image}$ and $Fluency_{text}$. Since our study only allows image clipping found objects, we only calculate the $Fluency_{image}$. An image clipping is uniquely defined as $[image_url\ source_url]$. $Fluency_{image}$ is measured as the number of elements of the set of image clippings in the curation.

Flexibility of a curation is measured in three levels of information granularity: *document*, *site*, and *site_type*. $Flexibility_{document}$ measures the diversity of source Web pages of the curated clippings. It is the number of elements of the set of *source_urls* in the clippings of the curation.

$Flexibility_{site}$ measures the diversity of the Web sites of source Web pages of the curated clippings by domain. Both 'money.cnn.com' and 'weather.cnn.com' has the same domain 'cnn.com'. But 'money.cnn.com' and 'www.google.com' has different domains. To calculate $Flexibility_{site}$, a set of the top-level Web domains is formed from the set of the *source_urls*. $Flexibility_{site}$ is the number of elements of the set.

$Flexibility_{site_type}$ measures number of unique categories of the Web sites of the *source_urls* of the clippings in the curation. The *site_types* of a *source_url* is obtained by checking the domain of the *source_url* against the OpenDNS domain categories. The set of the *site_types* of the curation is the union of the *site_types* of a *source_url*. And the $Flexibility_{site_type}$ is the number of elements in the set.

4. EVALUATION

Our user study evaluated the embodied cross-surface curation environment for collaborative ideation in what we call a *living-room lab* (Section 2.1.1). We recruited couples in a romantic relationship to design a home makeover plan. In this chapter, we first describe the user study design. Then, we explain our data collection and analysis methods. Next, we present the quantitative data from the study followed by the qualitative data from our observations. In the end, we show the feedback from participants on our interactive system.

4.1 User Study: Home Makeover Design

In the user study, we invited couples in an intimate relationship to collaboratively design a makeover for a shared living space using the embodied cross-surface curation environment. Participants went through the following procedure. First, they answered a pre-study questionnaire (Appendix E). Participants answered the questionnaire individually, without communicating with their partners. The pre-study questionnaire addressed previous experience of collaborative planning in participants' daily lives. It asked them what technologies they used and how they used them.

After participants finished the pre-study questionnaire, they watched a video tutorial to learn how to use the embodied cross-surface interactive system. Then each participant used a Nexus 7 tablet to practice a set of interactions introduced in the video tutorial. These interactions included: making connection between the tablets and the collaborative surface by touching the NFC tags, collecting rich bookmarks from the mobile browser, sharing rich bookmarks to the composition of the Embodied IdeaMÂCHÉ, viewing metadata and source web page of the rich bookmark in the composition, deleting rich bookmarks in the composition, sharing rich book-

marks back to the mobile devices, and adjusting the layers of rich bookmarks in the composition.

Once participants got familiar with the interactions, they started the main task of the study. Meanwhile, the video recording began. Each study session started with a clean composition space on the collaborative surface. Participants decided the themes of their home makeover projects. Since it was an open-ended task, there was no time limit on the task.

When participants finished their design, we conducted a short interview to ask participants a few open-ended questions about their experience during the design. Participants could also freely express their thoughts about the process. After the short interview, the video recording stopped.

In the end, participants would complete a post-study questionnaire (Appendix F). The post-study questionnaire gathered information on participants' feedback on each component of the interactive system as well as the overall system. Each couple received a \$30 gift card as compensation after they finished the post-study questionnaire.

4.1.1 Data Collection and Analysis Methods

We recorded video, audio, and captured the screen of the composition space on the collaborative surface. There were three video cameras monitoring the behaviors of the users. One camera was directly above participants and the television. It captured interactions close to and on the collaborative surface. The second camera with wide-angle lens was overhead to the left of the television. It captured movements of participants within the room. The third camera was directly on the television, facing participants to capture their facial expression, and body languages. Each video feed from the camera has a VGA resolution (640 by 480 pixels). The screen

capturing of the information composition has a FullHD resolution (1920 by 1080 pixels). We composited all the video and audio feeds into a single video stream using OBS [79]. The three video feeds from the cameras stacked vertically on the left of the composite video stream. The screen capturing was on the right to the cameras feeds. Figure 4.1 shows the screen shot of the video stream. We monitored the video stream in real time during the study in a room adjacent to the living room lab. We saved the logs of the interactive system as well as the products (the information compositions) of each study.

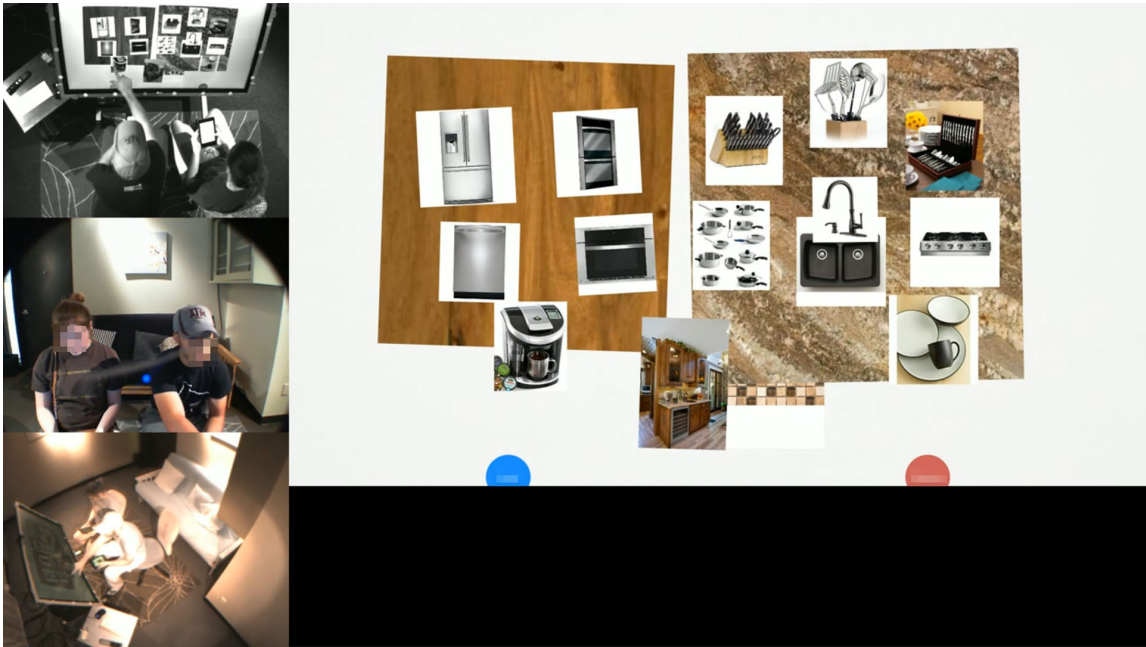


Figure 4.1: A screenshot of the recorded video stream for the study.

A grounded theory approach was used to study the quality of communication and other behaviors between participants in order to see how our system facilitate and support collaborative design [80]. A group of researchers watched the recorded video

after the study and combined the observations and the user feedback to evaluate their engagement in the embodied cross-surface interactive system. We investigated not only the final composition but also the progress of making the composition by analyzing how it helped the ideation process. We asked questions about the process. What rich bookmarks were added to the composition? What were their functions and significance in the design process? Why were they sometimes removed? Where and why did participants place them? How was the layout of the composition formed and changed?

In the initial stage of the data analysis, the researchers watched video recordings and identified interesting and significant phenomena. The first step was to compare and summarize those phenomena to generate a set of initial codes. Then these codes were applied to all the videos again to formulate theories. The coding process involved transcribing the conversation between participants, annotating their non-verbal communication including body orientations, gaze directions, gestures, and other body languages.

Additional data, such as interview, and questionnaire responses provided subjective opinions from participants before and after the study. These data were used to complement and compare with the findings from the observations. They could also disambiguate the uncertainties encountered from the video analysis.

The logs of the interactive system were analyzed to obtain temporal patterns and frequencies of interactions such as sharing rich bookmarks to the composition, manipulating rich bookmarks in the composition, and browsing metadata of the shared rich bookmarks.

Table 4.1: Demographic information of participants. * indicates that the duration of the relationship including the time of dating. † indicates that the couple brought their infant child to the study.

Group	Female Age	Male Age	Relationship	Duration
G1†	46	53	married	7 years
G2	21	21	dating	3 years
G3	28	27	married	4.5 years*
G4	28	31	married	8 years*
G5	27	30	married	13 years
G6	25	25	married	8.5 years*
G7	19	21	dating	13 months
G8	19	21	dating	3 years
G9	24	24	dating	9 months
G10	61	62	married	35 years
G11	44	42	married	25 years
G12†	31	37	married	7 years*

4.2 Quantitative Data

In this section, we present qualitative data from the study. We show the demographics of our participants and the statistics on the usage of our system. We also evaluate the fluency and flexibility of the information compositions created by participants.

Table 4.1 shows the age, marital status, and the length of the relationship. Two couples brought their infant child to the study. The participating couples covered wide range of age groups and length of relationships.

Table 4.2 shows the design topic and the duration of the design session of each couple. The average duration of a design session was 64.1 (SD = 16.3) minutes.

Table 4.3 shows the statistics of rich bookmarks shared and remained in the final information compositions. On average, each participant shared 0.27 rich bookmarks per minute. The Wilcoxon signed-rank test found no significant difference between

Table 4.2: Design topics and the duration of the design sessions.

Group	Design	Duration (mins.)
G1	Kitchen	84
G2	Bedroom	61
G3	Living-room	57
G4	Living-room	40
G5	Bathroom	48
G6	Living-room	46
G7	Kitchen	75
G8	Living-room	59
G9	Bedroom	72
G10	Kitchen	81
G11	Kitchen	55
G12	Garage/Storage room	91

Table 4.3: The number of rich bookmarks shared and the number of rich bookmarks remained in the final information by each gender with Wilcoxon signed-rank statistics.

	Male μ	SE	Female μ	SE	W	pi
Shared	16.1	2.0	18.3	2.3	22.0	0.35
In the final composition	10.3	1.7	10.6	1.6	36.5	0.88

genders for the number of rich bookmarks shared, and the number of rich bookmarks remained in the final information compositions. This shows that the amount of participation was statistically equal between the genders.

Table 4.4 and Table 4.5 list statistics of the $Fluency_{image}$, $Flexibility_{document}$, and $Flexibility_{site}$ of the curations created in the studies. We follow the methods in Kerne *et al.* [1] using the Image Fluency and Flexibility metrics described in Section 3.4. But instead of calculating the metrics based on rich bookmarks in the final information composition, we calculated the metrics based on all shared rich bookmarks during the study sessions. We thought the process of the ideation was

Table 4.4: Elemental ideation metrics of curation for design processes for each gender with Wilcoxon signed-rank statistics.

Metric	Male μ	SE	Female μ	SE	W	p _i
Image Fluency	15.1	1.9	17.1	2.5	17.5	0.33
Document Flexibility	15.1	1.9	15.1	1.8	21.5	0.95
Site Flexibility	6.0	0.7	4.4	0.9	33.0	0.23

Table 4.5: Elemental ideation metrics of curation for design processes for each individual and the group.

Metric	Individual μ	SE	Couple μ	SE
Image Fluency	16.1	1.5	31.9	3.9
Document Flexibility	15.1	1.3	29.9	3.1
Site Flexibility	5.2	0.6	8.5	1.2

as important as the result. The number of rich bookmarks in the final information composition alone did not faithfully reflect the contribution of each participant to the curation and design process. Participants frequently added and removed rich bookmarks from their information compositions while performing the task. Removed rich bookmarks also contributed to the ideation process.

There were no statistical differences of the ideation metrics between two genders. The Image Fluency and Document Flexibility for the couple were approximately equivalent to the sum of two genders, indicating that participants mostly shared rich bookmarks with different source documents from their partners. The Site Flexibility of each couple was less than the sum of the two genders, indicating that the Web sites that two partners curate rich bookmarks from often had overlap. However, it still showed that collaboration led to higher creativity than individual work since rich bookmarks came from more Web sites.

Participants used the in-context metadata and Web browser to take a look at

the metadata or the Web page of rich bookmarks in the information composition (Section 2.2). Participants viewed the metadata 11.2 (SD = 6.5) times on average. Participants spent 21.7 seconds each time on a metadata. Some participants frequently used the in-context metadata and Web browser to view the Web pages but the others not. Participants browsed the web page 2.8 (SD = 3.6) times on average during a session. Each time, participants spent 60.6 seconds on the web page on average. Although participants opened the Web page less frequently than they opened the metadata. They spent longer time on the Web page each time.

4.3 Qualitative Data

The embodied cross-surface interaction technique helped participants by affording flexible collaboration and communication during the design process. Unlike other collaborative systems that require participants to use the system in certain formations (i.e., always sitting or always standing close to the collaborative surface), in our system, participants displayed many forms of positions, and they often changed positions, moved around in the study environment.

Although there were multiple devices to deal with, participants shifted their attention among the mobile devices, collaborative surface, and their partners without losing focus of the tasks. They went back and forth between the personal and the collaborative surface, as well as engaged in face-to-face communication with their partners. We observed diverse communication methods from participants. The embodied cross-surface curation environment allowed them to be themselves during the collaborative design process. For example, we observed that participants were making jokes in multiple occasions.

Conflicts are unavoidable during collaboration, especially in a system that allows working in parallel. The success of the collaboration depended on the active

coordination between two participants to resolve conflicts. The diverse ways of communication afforded by our interactive system allowed participants to resolve conflicts naturally through verbal communication and embodied interaction. The process of conflicts resolving created the intimate moments for the couples. Participants dealt with the individual and common needs to exchange ideas and keep the design flowing.

Besides verbal communication, participants also used their fingers to do the talking. They used rich bookmarks and information compositions as media to express their design ideas. They perceived different roles of rich bookmarks in the information composition. They used rich bookmarks to set the theme of the design, to inspire them, and to express ideas to their partners.

Participants used the information composition as an expressive design medium. They grouped rich bookmarks together in meaningful ways. They arranged rich bookmarks in the composition to map the physical space of the room that they designed. They created temporary storage space in the information compositions to compare and filter the shared information. Rich bookmarks and information compositions help participants store, organize, and sift through their design ideas using embodied interactions. They helped participants generate more ideas during the design processes.

4.3.1 Flexible Formations in Collaborative Design

We found that co-located participants using the embodied cross-surface curation environment in the living room lab formed F-formations during collaboration (Section 1.6). We observed different F-formations between participants in the study. Participants fluidly switched among different formations in the course of a single session. This shows that our system supports peoples' engagement with information in flexible formations.

4.3.1.1 F-formation Varies by the Needs

We observed that the F-formation formed by participants vary by their needs during the session. For instance, Figure 4.2 shows F-formation in which two participants staying within close distance to each other and the collaborative surface. In this F-formation, the o-space covers the common space surrounded by participants and the collaborative surface. Participants oriented their upper bodies towards the collaborative surface and also slightly towards each other.

Sitting slightly towards each other made it easy for participants to make eye contact with their partners and check their partners' responses during the conversation with minimal need to reorient their heads and upper bodies. Because they were close enough to the collaborative surface to reach it, they could readily switch their attention and work between their tablets and the collaborative surface. We often observed that both participants worked on their tablets (Figure 4.3), both on the composition (Figure 4.4), or one participant on the tablet and the other on the composition (Figure 4.5).

In this formation, both participants were able to work on the tablets to collect rich bookmarks as well as on the collaborative surface to change the information composition. They could also show their tablets to their partners (Figure 4.6) to let them view an interesting web page, or get their opinion. When showing the tablets to the partner, the two participants were closer to each other than when they were working independently on tablets. One participant tilted his / her tablet towards the partner, so that both participants could see the screen.

In another common F-formation, one participant resided the space away from the collaborative surface, behind the other participant who was close to the collaborative surface (Figure 4.7). In this formation, the transactional segment of the participant

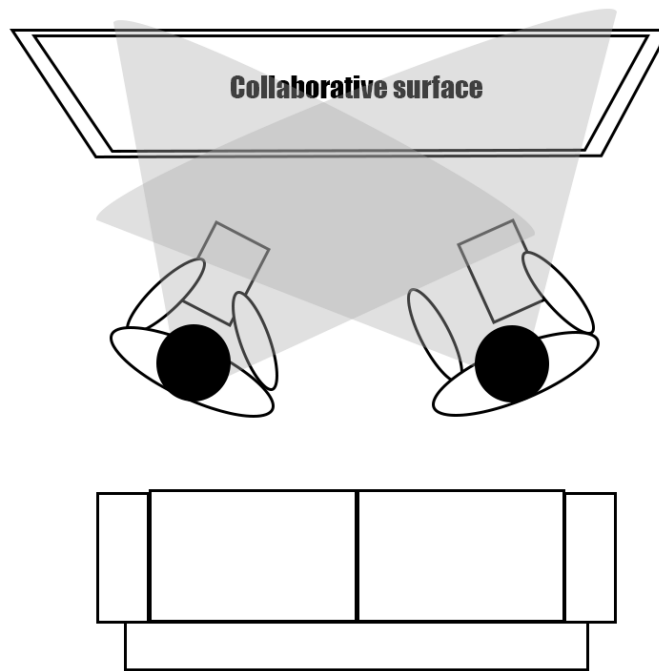


Figure 4.2: F-formation with both participants staying close to the collaborative surface. The gray area shows the transactional segment of a participant. The darker gray area shows the intersection of the transactional segments. It is approximately the o-space. The exact transactional segment of a participant varies depending on his body orientation. While both participants are in the Flexible Configuration Zone, they often move into the Collaborative Surface Zone together or individually.

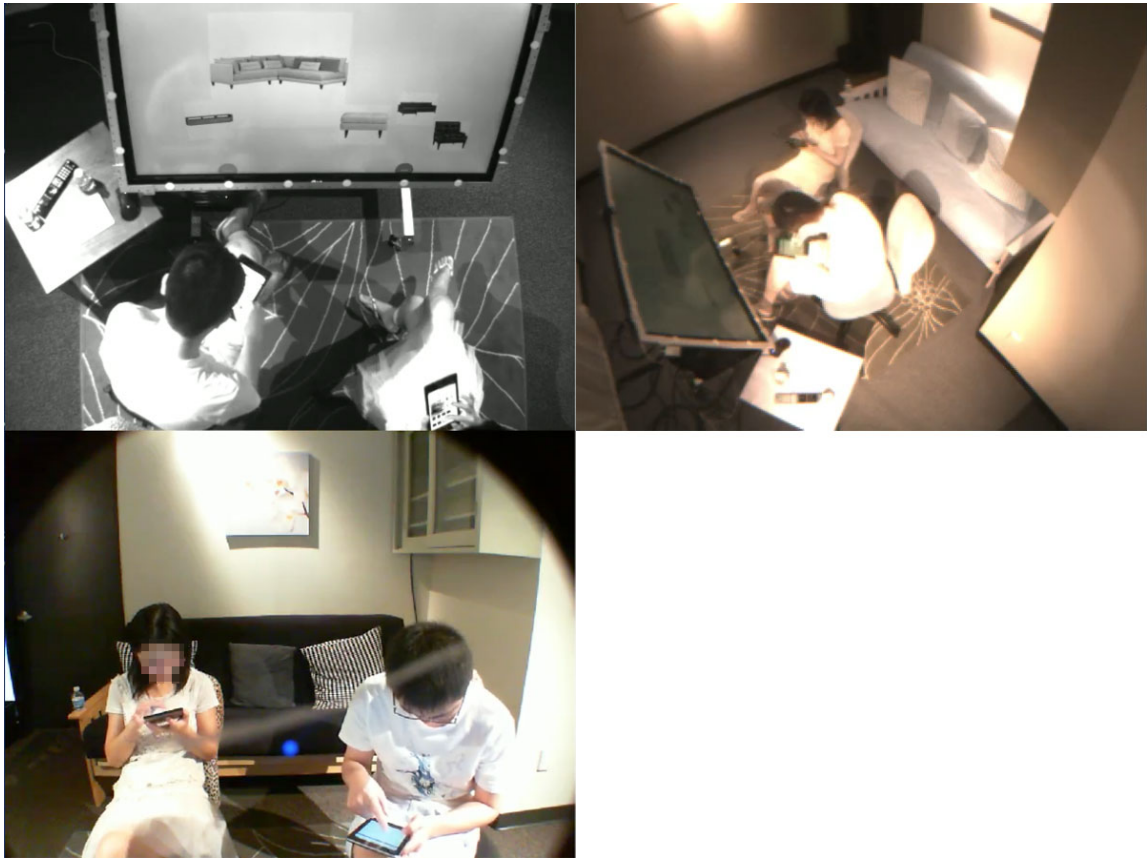


Figure 4.3: Both participants working independently on their mobile devices.



Figure 4.4: Both participants working on the composition.

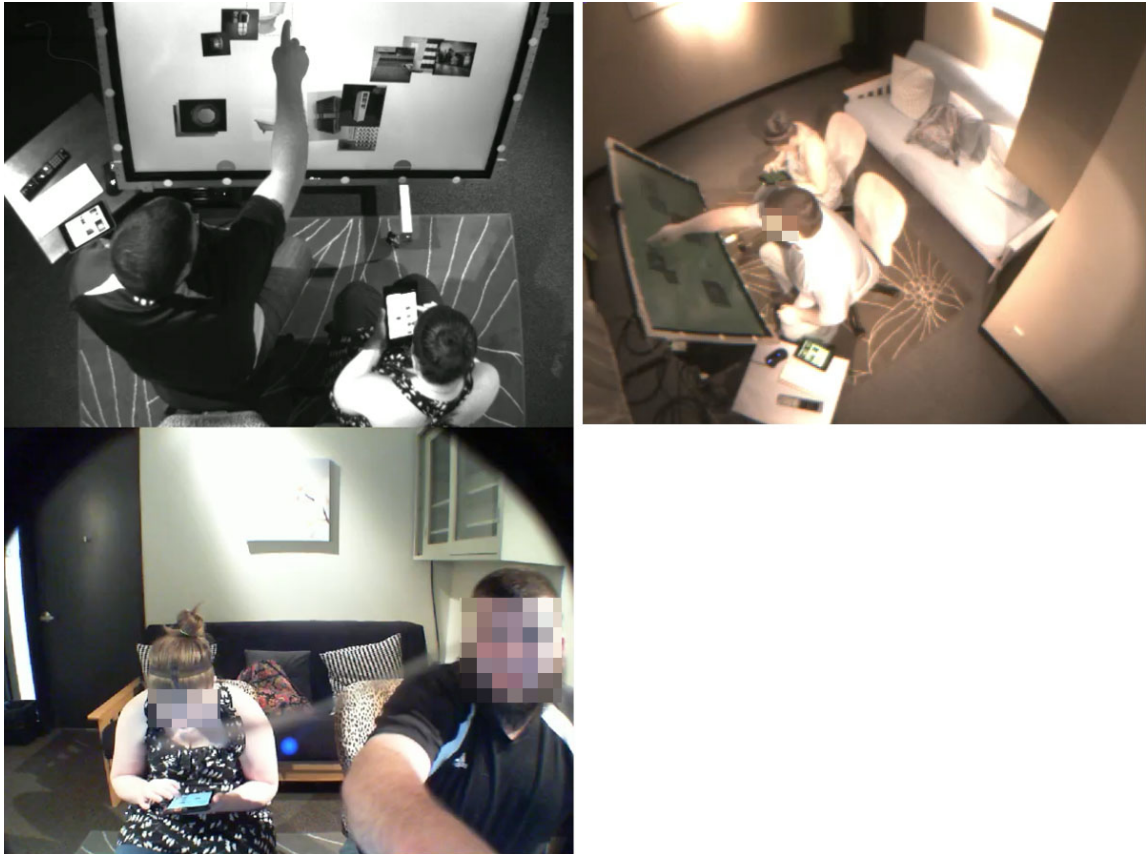


Figure 4.5: One participant working on the composition while the other participant working on the mobile device.

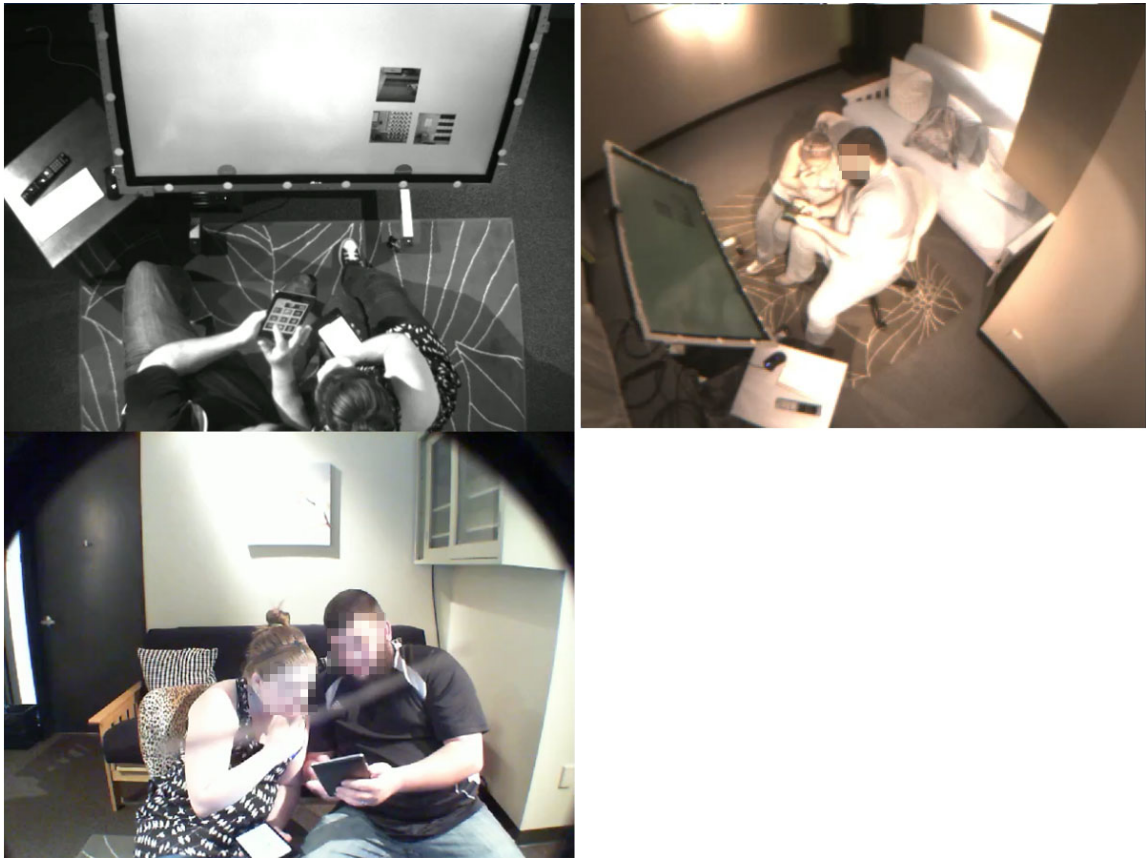


Figure 4.6: One participant sharing the mobile device with his partner.

who was away from the collaborative surface covered a larger area than the one of his partner. It also covered most of the transactional segment of his partner. The participant away from the collaborative surface monitored both the collaborative surface and his partner. On the contrary, his partner did not monitor his interaction as often because he was outside of his partner's regular transactional segment. His partner need to turn around to engage a face-to-face communication.

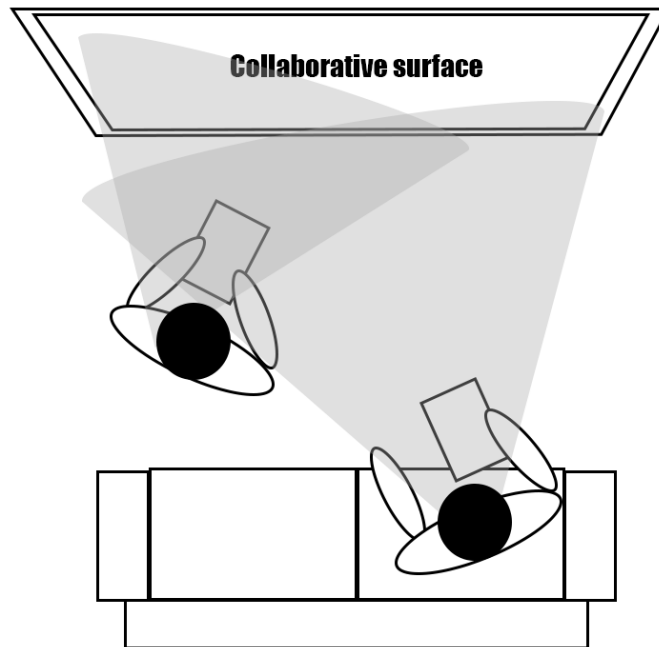


Figure 4.7: F-formation with one participant staying behind the other participant who is close to the collaborative surface. One participants is close to the Collaborative Surface Zone. The other participant can move out of the Flexible Configuration Zone and sit on the couch.

We found that in this type of F-formation, participants engaged in sharing the tablets screen fewer than the previous formation. But the cross-surface interaction allowed them to use other methods to share information. For example, in one session, the participant who was sitting close to the collaborative surface shared rich bookmark through the portal to his partner, who was sitting on the futon. On the other hand, whenever his partner wanted to share rich bookmark to him, she simply shared it to the collaborative surface.

This F-formation was often formed by the couples who had different needs during the design process. In one session, after an initial coordinating period, a participant moved from his chair to the couch. He focused his work on the tablet. He collected and shared several rich bookmarks of various designs of kitchen tiles to the composition. Each time he shared, he would ask his partner, who was sitting close to the collaborative surface, to look at the rich bookmark. She would make comments on rich bookmarks and manipulate them on the collaborative surface, even though they are on the other side of the composition close to her portal. He said that he felt the couch was more comfortable, and there was no immediate need for him to manipulate rich bookmarks on the composition, but he could still contribute to the collaboration process by sharing collected rich bookmarks to the composition and discuss with her partner. However, she chose to stay on the chair because she preferred to have the hands-on experience all the time.

We also observed another type of F-formation where both participants sitting on the futon, away from the collaborative surface (Figure 4.8). When both participants were away from the composition surface, their transactional segments both covered a large area from them to the collaborative surface.

Couples chose this formation when both of their needs were mainly on collecting rich bookmarks on the tablets. The workflow of their design process was also

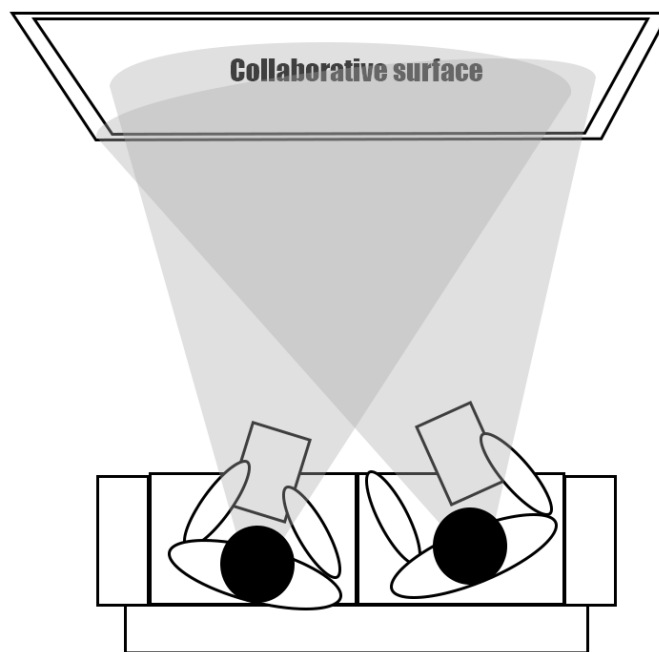


Figure 4.8: F-formation with both participant staying in the Physical Intimacy Zone.

different from the couples in the other formations. They shared rich bookmarks from time to time using cross-surface sharing technique. When they both sit on the couch, they engaged in conversation and showing each other their mobile devices like other formations like they could when they were both close to the collaborative surface (Figure 4.9 (a-b)). They only walked to the collaborative surface to make change occasionally (Figure 4.9 (c-d)). After changing the information composition, a participant would move back to the futon. Near the end of the session, when both participants felt that they have shared enough rich bookmarks, they both got close to the collaborative surface to make final changes (Figure 4.9 (e-f)).

4.3.1.2 Spatial Organization Suggests Rights and Roles

The choice of where the head and body oriented and the distance between the partner and the collaborative surface suggested the role a participant wanted to play in the collaboration, and the rights he was claiming.

In the F-formation shown in Figure 4.2, both participants were taking active role of collecting information as well as working on the composition. Their rights in the design process were also similar. Sometimes in this formation, one participant left her seat and stood up during the study session. She put down her tablet and interact solely with the multi-touch collaborative surface (Figure 4.10). She moved into the his partner's transactional segment between him and the collaborative surface, preventing him from reaching the collaborative surface. By standing up and taking a dominating control on the information composition, she demonstrated superior rights in the design process.

In the case of F-formation shown in Figure 4.7, a participant stood in the back of her sitting partner. The roles of the two participants divided. By staying away from the collaborative surface, she yielded to her partner to let him have the predominant



Figure 4.9: (a-b) Both participants sitting on the couch, away from the collaborative surface to work on the tablets. (c-d) One participant sitting on the couch while the other moving close to the collaborative surface to change the information composition. (e-f) both participants standing in front of the composition to make final touches.

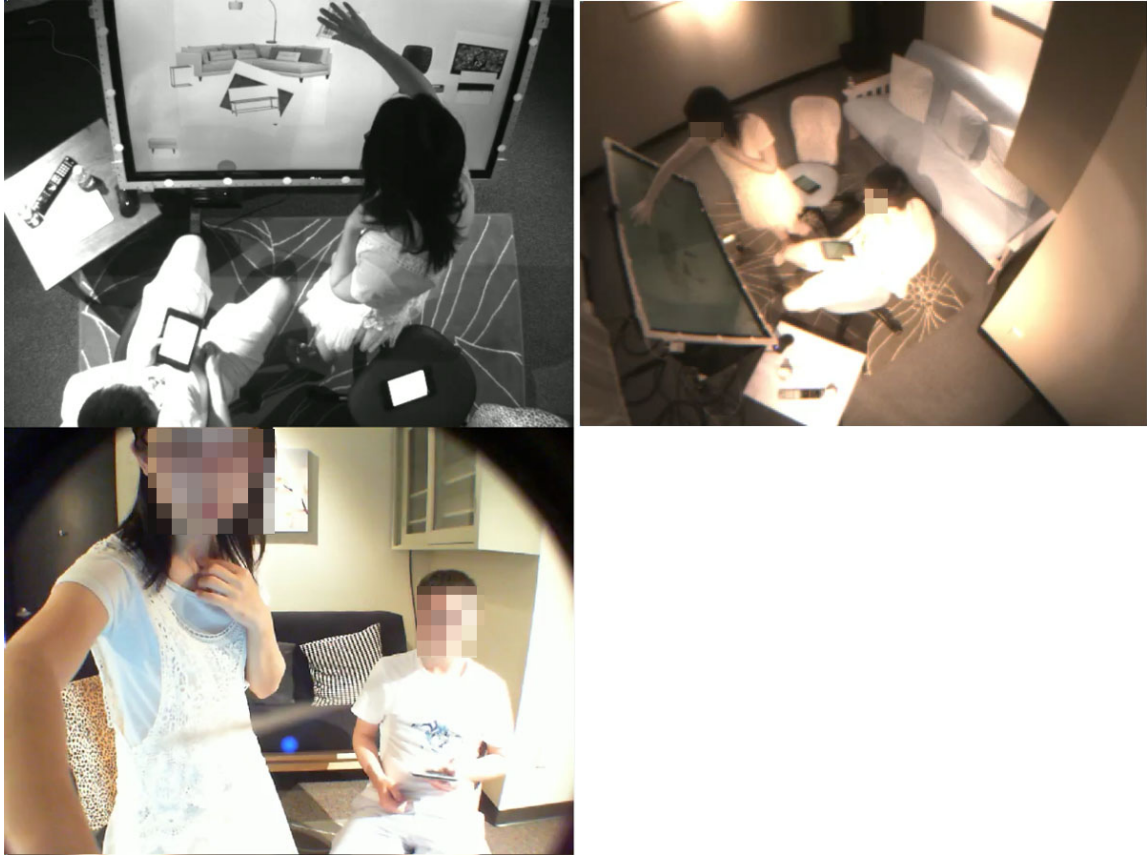


Figure 4.10: One participant standing in front of the collaborative surface to work on the composition, while the other sitting on the chair.

rights to interact with the composition. As a trade off, she gained more free space to walk around, and she could focus on collecting rich bookmarks. Even though she was away from the collaborative surface, she still retained the rights to share rich bookmarks to the information composition using cross-surface sharing technique. When she wanted to change the composition, she could walk up to the collaborative surface, or ask her partner to do it.

4.3.2 Shifting and Getting Attention are Lightweight

While flexible formations freed participants from maintaining static positions and roles during collaboration, participants still need to monitor the actions of their partners and emergent situations in the environment during design processes. Multi-touch and multi-user interfaces could challenge participants in how they direct their attention. These interfaces could diminish attention participants would otherwise give their partners. They were found to demand higher peripheral awareness from participants [81].

However, despite frequent needs to shift attention between multiple surfaces and the partner, as well as the need to obtain attention from the partner, we found that attention shifting and obtaining were lightweight in our studies. They did not demand high awareness from participants or distract participants from the work they were doing. They did not require much physical movement either. Participants frequently shifted attention among their partners and the personal and collaborative displays. We did not observe that participants were unaware of their partners' interaction in the collaboration.

4.3.2.1 Shifting Attention

In our study, participants shifted attention in the following situations: a) to work on a different screen; b) to monitor a partner's work on her/his personal surface; c)

to monitor changes in the joint composition; d) to respond to a partner's inquiry.

When a participant was curating rich bookmarks using the mobile device, his partner might be making changes on the information composition or making gestures to get his attention. Even though the participant's attention was mainly on the tablet, in our designed system (See Section 2.1), his peripheral vision gave him awareness of the changes in the information composition and his partner's movements without losing focus on his work on the tablet. We observed that it is lightweight for a participant to shift his attention among the tablet, the collaborative surface, and his partner.

We observed that when a clipping was shared to the information composition, the animation of it sliding on to the collaborative surface (Figure 2.9) often attracted participants who were collecting rich bookmarks on their tablet. If they felt like to work on the updated information composition, they would pause their work on the tablets, and switch their attention to the collaborative surface.

We also observed that participants frequently glanced at the compositions or their partners' tablet to monitor their partners' work when the web pages were loading on the tablets, or when they paused to think about the next design idea, or in other cases when they had the opportunities to not focus on the tablet momentarily. While holding a tablet, participants could easily turn their heads and bodies to the collaborative surface to work on the information composition, or to their partners to engage in discussion. Participants used the tablet during their discussion with the partner. They often shared the tablet screens with their partners.

Because the spatial relationship of the tablet and the collaborative surface and the embodied sharing gesture (See Section 2.3.2), a participant could easily shift his attention from the tablet to the collaborative surface after sharing a rich bookmark. For example, when a participant shared a rich bookmark to the collaborative

surface, his attention naturally moved from the mobile device to the collaborative surface (Figure 4.11). At that moment, he could seized the opportunities to make small changes on the information composition, such as moving the newly shared rich bookmark to a nearby empty space to reduce overlap among clippings in the composition, or removing the previously shared rich bookmarks that were no-longer needed.

4.3.2.2 *Obtaining Attention*

Asking for a partner's opinion was essential to the collaboration. This behavior reduced conflicts that might later arise. While participants were working independently on their mobile devices, collecting information, they also periodically tried to elicit each other's opinions. Sometimes a participant wanted to get a quick opinion from her partner after sharing a rich bookmark to the information composition. However, her partner was perhaps working on his tablet at that moment. He could look up at the composition for a quick glance, make a comment, then switch immediately back to his work on the tablet. The work he was working on stayed on his tablet, so he could continue with minimal interruption.

In other cases, a participant wanted to get her partner's opinion on the mobile device, she moved close to the partner and shared the screen of the tablet. In one example, the husband was focusing on a web page, he wanted the wife's idea, so he showed his tablet to her (Figure 4.6). The wife pointed several items that she liked, then turned back to her own work. The husband explained his behavior later, "*She is an artist. I'm not. I appreciate aesthetics, but I think she has more aesthetic sense. I try to make sure she's happy. Sometimes I know I really want this, but most of the time I make sure it goes well with what's in her mind.* "

One participant described her collaboration style, "*I showed my favorite item to*

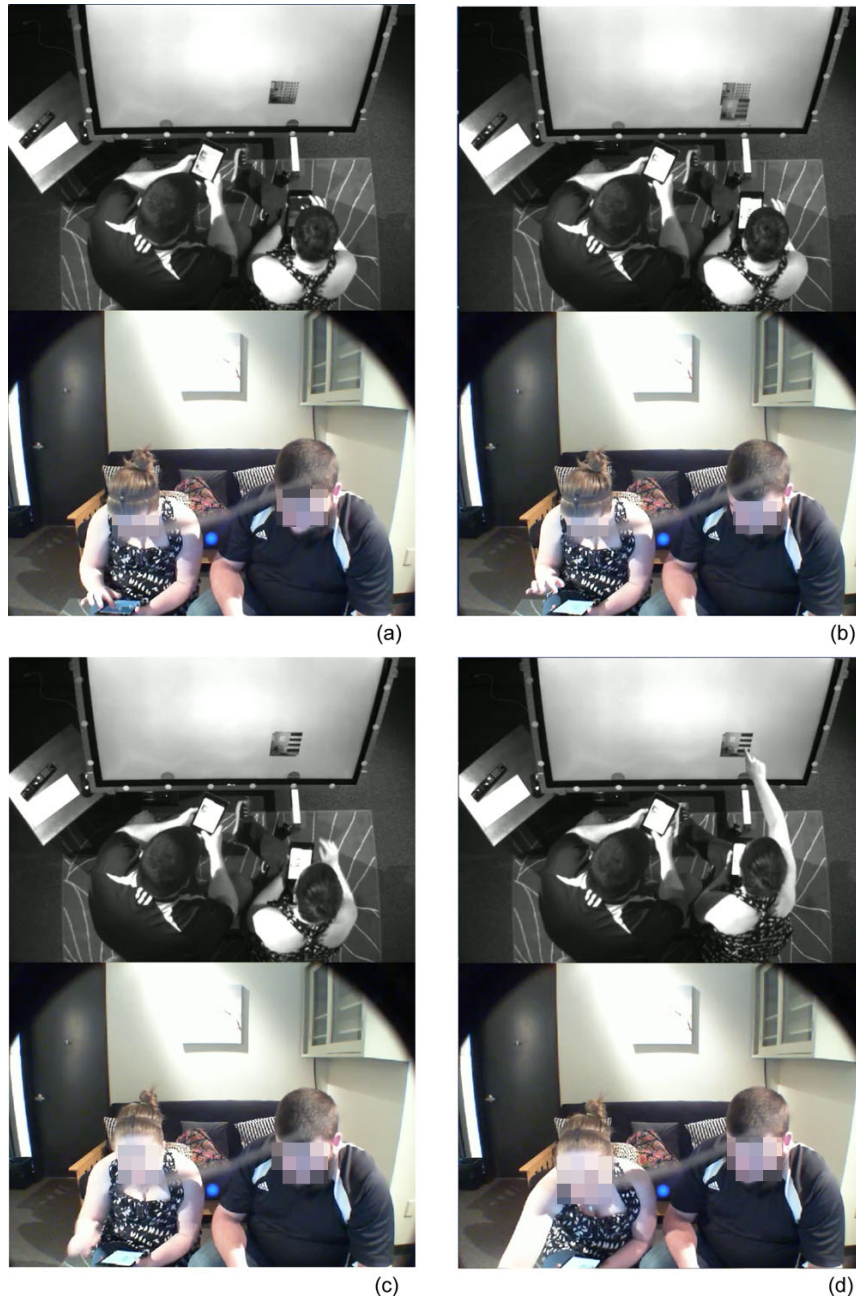


Figure 4.11: A user shared a rich bookmark from the mobile device to the composition. Her attention naturally shifted to the composition.

my partner before I shared it to the system to find out whether he likes it or not. ”

However, we observed that she only correctly described her behavior in the beginning of the session. As the session went on, however, she shared rich bookmarks directly to the composition without asking her partner before sharing, indicating that she was getting comfortable in this cross-surface composition paradigm with independently expressing her opinion.

Sharing rich bookmarks to the partner was another way of getting attention. This is useful when the two participants were not sitting close to each other. In one session, a participant was sitting in front of the collaborative surface while the other sitting farther away from the collaborative surface on the futon. The one who was close to the collaborative surface often used the sharing function to send rich bookmarks he found interesting to his partner.

4.3.3 Diverse Ways of Communication

Collaboration involves many natural forms of communication between users, including verbal communication and non-verbal communication like gesturing. One fear of using cross-surface technology is that devices occupy users' attention, and distract them from face-to-face communication with other users during collaboration. Instead of distracting users, the embodied cross-surface interaction in our system provided natural interface to facilitate face-to-face communication (See Section 1.4). The sharing gesture to transfer rich bookmarks across devices and manipulating rich bookmarks in the joint information composition were intuitive, direct and physical. In our study, we observed participants engaging in natural human forms of communication while interacting with computing devices.

A primary function of verbal communication was to ask a partner's opinion on the design, and initiate discussion. In this form, when a participant finished talking,

s/her expected her partner to respond. Participants used verbal communication to schedule subtasks. In the cross-surface system, the surfaces became a focus of discussion. We observed that participants shared their personal surfaces with their partners to discuss found objects from the Web. Participants talked about the objects shared in the composition throughout their collaboration. However, the discussion did not always focus on the objects that were already curated. Participants often discussed emergent ideas inspired by the objects they found during the design. They brought their prior experiences to the discussion.

Another category of verbal communication did not require a partner's response. Participants frequently announced their next move with think-out-loud during the collaboration. This enabled partners to be aware of what they are working on without interrupting. For example, while using a tablet, a participant talked out loud what she was going to look for, what web page she was looking at, or whether she liked a particular item on the web page. While sharing rich bookmarks to the composition, participants often announced this action by saying, "I want this one", "Let's see how it works with [something]", or "Look what I found". Similarly, while working on the composition, participants tended to verbalize their intentions and actions even without securing their partner's attention. They explained their reasons when they made changes to rich bookmarks on the composition. This form of narrative talking occurs naturally in our daily lives. The frequent occurrence during the study indicated that participants felt comfortable and natural while using the cross-surface system.

We observed multiple occurrences in which participants talked about topics not directly related to the study. They made jokes to please each other and ease the atmosphere. Other times, participants engaged in intense verbal debate to defend their ideas. These further indicated that participants felt sufficiently comfortable

during the collaboration.

Non-verbal communication methods often accompanied verbal ones. rich bookmarks and the composition served as a medium through which participants communicated with each other. Sharing to the composition periodically gave each partner a sense that his partner was actively involved in the design process. When a participant kept collecting rich bookmarks without sharing for a long time, it frustrated his partner.

By changing rich bookmarks' size, orientation, and position in the composition, participants expressed their ideas without talking. For example, in one session, the female participant reorganized rich bookmarks based on their colors. When the male participant saw this, he approached the composition and helped his partner by making similar changes. All happened without verbal communication.

The size and the position of rich bookmarks indicated their importance in the joint information composition. By making a rich bookmark larger and placing it close to the center of the composition, a participant showed that it was more important than a smaller rich bookmark close to the edge of the collaborative surface. We will discuss more about using the information composition to express ideas in the following section.

4.3.4 Active Coordination to Resolve Conflicts

Prior researchers developed coordination policies and techniques beyond 'social protocols' for multi-user interface to resolve conflicts, protect objects and territories, thus enforce equal participation [48, 49]. These policies and techniques were desirable in their study cases since their study participants were classmates or colleagues. However, our participants were very different. Resolving conflicts through communication is an essential part of romantic relationships and other sustained meaningful

relationships.

Our system relied on participants themselves to coordinate to solve these conflicts. By not strongly enforcing coordination policies, our embodied cross-surface curation system minimally interfered with how participants preferred to deal with conflicts. Intentional and accidental conflicts sometimes brought unexpected benefit to the collaboration. Letting participants to resolve conflicts through communication was vital to their engagement in their collaborative design. The limited space of the collaborative surface did not always fit all the items collected throughout a design session. Participants reflected, and transformed their composition from time to time. When both participants were simultaneously working on a composition, the multi-touch modality provided them with the opportunity to effectively work in collaboration.

4.3.4.1 Many Ways to Coordinate

We observed coordination behaviors that included both formal ones that showed respect to partners, and informal ones that showed the intimacy between a couple. When both participants wanted to manipulate a rich bookmark, in the formal or polite coordination, a participant waited for his partner to finish her change, and then worked on the same rich bookmark. He usually explained the reason that he made the further change. However, he might not explain if the reason was obvious (i.e. making a rich bookmark tilt upright).

As the example of the informal coordination, a female participant had dominant control of the composition while standing. When her partner intended to make changes to the composition, she knocked his hands off from the collaborative surface to regain control.

On the collaborative surface, we observed that both participants contributed to

the layout of the composition. They could both contribute to the same area of the composition or they could do differently. We often saw that one participant contributed more to the big picture and the overall layout of a composition while the other focused on the details. Multi-touch capability enabled and ensured that both participants had concurrent access to manipulate rich bookmarks on the collaborative surface. They could interact with the composition simultaneously (as shown in Figure 4.12) or took turns to change rich bookmarks to express their ideas.



Figure 4.12: Two participants simultaneously interacting with different objects on the composition.

4.3.4.2 Spontaneous Collaboration without Coordination

Conflicts did not always cause negative effects to productivity. Spontaneous collaboration often occurred. Two participants could successfully collaborate on

manipulating one rich bookmark simultaneously without intentional coordination. In this example shown in Figure 4.13, the male participant shared a rich bookmark to the composition, and attracted his partner's attention. He moved the rich bookmark to the center of the composition, and asked how to make it bigger. Meanwhile, she leaned towards the collaborative surface to touch the same rich bookmark. Usually, simultaneous touching by two participants would cause conflicts. However, in this particular case, the two participants moved their fingers in two opposite directions, which unexpectedly led to the desired results. Both participants were satisfied. He said, *"That's exactly what I want."* It ended up with both participants smiling. This kind of spontaneous collaboration resulted in intimate moments, which resulted in an overall satisfying experience for participants.

Some forms of coordination were non-verbal. When participants wanted to conduct interaction on the composition for an extensive period, or use both hands, they would put aside their mobile devices. We observed in one session that one participant looked at the composition. His body turned towards his partner and extended his hand that held the mobile devices. She immediately got his intention and held the mobile device for him while he was working on the composition.

One interesting moment occurred during a session, when a participant looked over her partner's shoulder to watch his mobile device. She liked the rich bookmark that the husband had just collected. Before she made the sharing gesture (Section 2.3.2) The design of the sharing gesture takes into account the spatial relationship between the mobile device and the collaborative surface, making it easy for participants to perform the gesture, each on the other person's device!



Figure 4.13: An example showing participants interacting with the same rich book-marks without explicit coordination.

4.3.4.3 *Asking for / Giving Help*

Active coordination during the collaboration improved the efficiency. Sometimes, after interacting with a rich bookmark, a participant would ask her partner for help to make further improvements. Some examples would be: ‘move it to the back’, ‘rotate the mirror to align with the closet’, etc. Participants also asked their partners for help. For example, a participant would ask his partner to move or change a rich bookmark that she could not reach.

While working on similar tasks, a rich bookmark collected by one participant often subsequently inspired his/her partner. A participant could help his partner find a particular object on the web. Since both participants had their own mobile device to collect information, each of them could also pursue his/her own specific information need, in the context of working toward a common goal. For example, when designing a garage / storage space, the husband took the lead in looking for exercise and fitness devices, the wife was looking for storage frames (Figure 4.14).

4.3.5 *The Many Roles of Rich Bookmarks*

Rich bookmarks convey the ideas of participants in the information composition. The present study differed from the previous studies on the information composition. In the previous studies, the participant work individually on the information composition. The researchers could only see the final composition. The final composition was the only way the ideas were expressed to other people. In this study, participants expressed ideas to each other during the task. The changes of rich bookmarks and the layout of them in the information composition provide much more information than a final information composition. The whole design processes were recorded, which gave researchers the opportunities to investigate the functions of rich bookmarks during the design processes.



Figure 4.14: Two participants were working on separate tasks in parallel.

In the previous study, Webb et al. [9] found that rich bookmarks, visual clippings with metadata, like those in the present research, provide concise representation as a unit of curation. They encourage flexible and ambiguous interpretations to promote divergent thinking. Creatively choosing and collecting a rich bookmark promotes reflection and interpretation. Webb et al performed a study of individual participants performing an entrepreneurship ideation task in an educational setting. Students collected rich bookmarks individually.

We found that rich bookmarks played several different roles in the collaborative design process. Rich bookmarks that were shared and kept in the shared information composition for an extended period played thematic and conceptual roles in the emergence of a couple's home makeover design. Some rich bookmarks were kept for only short period in the shared composition. While participants might not have kept them in their final product, in many cases these transient rich bookmarkers

nonetheless stimulated participants to explore and find other ones. Throughout the design process, participants used rich bookmarks to help them express their ideas to their partners. They often let rich bookmarks do the talking.

4.3.5.1 Rich Bookmarks Serve as Focal Points

A rich bookmark was used as a focal point in a design. Just like real furniture or appliances in a room, rich bookmarks of a television or a couch were often used for this purpose. Participants usually considered these big furniture and large appliances first in a home design. Likewise, rich bookmarks representing such objects shared by a participant in early stages of the design process became very important to the entire design.

For instance, one female participant shared a rich bookmark of a white couch to the composition early in the design session. She announced, “I think we have picked our couch.” Later, newly shared rich bookmarks were placed around the couch. These rich bookmarks were all with similar color theme to the couch to match its style.

In another session, a couple shared a rich bookmark of an artwork that said “Mr. and Mrs. ”. Although they shared and then removed many other rich bookmarks, this artwork stayed in the conspicuous position in the composition. It indicated that both participants treasured their relationship and wanted to express it in their design.

4.3.5.2 Expressing Ideas Using Rich Bookmarks

Participants iteratively ideated in response to provisionally curated information, represented their ideas in the form of rich bookmarks, then expressed and articulated their ideas to their partners by sharing rich bookmarks. Since the rich bookmark carried meanings visually and through layers of context, participants were able to show their partners a rich bookmark in lieu of explaining an abstract concept. For

example, in this session, a participant could not find a piece of furniture with a specific color. In order to ask her partner for help, she shared another item with the same color to the composition so that they could use it as a reference.

Participants could further express their intentions through manipulation of rich bookmarks. For instance, we often observed participants temporarily enlarging rich bookmarks to show their partners the importance of an object. In previous study, Webb *et al.* also found that participants enlarged rich bookmarks to emphasize their importance [9]. In our study, resizing a rich bookmark could also be used to express an idea temporarily to one's partner. Participants could change the size back after the ideas was received.

4.3.5.3 Rich Bookmarks Stimulate Collaborative Design

We observed a phenomenon in which some participants shared a rich bookmark with a rich bookmark showing an already designed room. Participants used the example designed room as a conceptual springboard to stimulate their collaborative design. Participants then discussed what they liked in the image, and started looking for similar objects and design inspirations. Some rich bookmarks curated in this way were only kept in the composition for a short period. As an example, in one session, the male participant shared a rich bookmark of a fully designed room to the composition. The female participant told him that she did not like the darkness and the traditional style of the furniture in the room. They also found that they both liked the floor light. So they started to browse for a similar floor light on the Web to add to their design. It is difficult in general to express and receive ideas about subjective features, like the theme, the mood or the style of a living space, to or from other people through only verbal communication. A room may be too dark for one person but too bright for another. A piece of furniture that is modern to one person

may not be modern to another. Using examples helped articulate the ideas to the collaborator.

4.3.5.4 Rich Bookmark Leads to Ideation

Rich bookmarks could also lead to ideation and discussion on the topics that went beyond rich bookmarks themselves. In one example, the husband shared a rich bookmark of a range oven and moved it close to a clipping of a kitchen cabinet. The wife immediately related their house to this design. She asked her husband about the work needed to be done to accommodate the oven. They went so far as to talk about which wall was not weight bearing so that it could be remodeled.

4.3.6 Collaborative Design Using Joint Information Composition

In a previous study on information composition for a single user, it was discovered that organizing rich bookmarks in a meaningful way expressed ideas [9]. Rich bookmarks understood relationships among collected ideas via reflection and interpretation, then expressed these relationships via manipulating the visual features of rich bookmarks, such as location, orientation, and size in an information composition. Positioning rich bookmarks enabled the curators to discover emergent relationships among the collected information.

In our study, the information composition contained rich bookmarks curated by both partners, making it the place where their ideas collided and evolved. We observed that participants used the composition to help them collaboratively store, organize, and sift through their design ideas. Participants re-arranged the shared rich bookmarks into meaningful groups. They compared their own curated rich bookmarks with those shared by their partners. Participants' ideation processes were stimulated not only by their own, but also by their partners' interactions. These processes promoted emergent idea [82].

4.3.6.1 Temporary Territories

Participants established temporary territories on the information composition early on. They used transient empty space as temporary storage. One common behavior from participants was that they established territories on the information composition in early stages of design. Participants often divided the composition into two halves. Each half contained mostly rich bookmarks shared by the participant sitting close to that side of the collaborative surface. However, this territoriality of the composition was in many cases only temporary. The division blurred after some time, as participants moved rich bookmarks around in the composition. However, we found that in a few cases, strong territoriality remained throughout a couple's design process.

4.3.6.2 Transient Storage Space

A design process style that contributed to dynamic changes in the composition involved the transient space participants used to temporarily place rich bookmarks. We observed different patterns of creating such space. When there were too many rich bookmarks on the composition, participants moved rich bookmarks that were currently not in use to the edges and corners. As an extreme case, one participant cleared up half of the composition to make room for creating a layout, and put rich bookmarks that were not used in the other half of the composition. Sometimes, participants removed rich bookmarks to make room, since they knew that they could bring them back when needed from their mobile collections.

Another method to create temporary storage space for rich bookmarks was panning the composition. By panning the composition, participants always kept their focal center in the middle of the collaborative surface. However, it had disadvantages, because participants could not see rich bookmarks outside the displayed space.

4.3.6.3 *Experiment with Ideas Spatially*

Participants arranged rich bookmarks in different spatial layouts in the information composition to present and experiment with ideas utilizing the spatial relationships of rich bookmarks. During the design process, we observed highly dynamic changes to the layout of the information compositions as well as the forming and dissolving groups of rich bookmarks. Groupings have been found to function as an important basis for the formation of emergent ideas in information-based ideation [82]. They frequently put different rich bookmarks together to see how they matched each other in color and style. Different ideas were tested, and unwanted rich bookmarks were removed from the composition. Participants often changed layers of rich bookmarks to better visualize the results of combination of rich bookmarks.

Rich bookmarks in the compositions often contained strong spatial relationships. The layout of rich bookmarks in the compositions reflected the spatial layout of the room in most cases. The composition usually appeared in an overhead view or birds eye view. In these cases, participants referred the top part of the composition as the back of the room, and the bottom of the composition as close to themselves. For example, Figure 4.15 shows a layout of a bathroom.

Participants also used the layering of rich bookmarks to express and visualize ideas. The workspace of the information composition is a ‘flatland’ while a room that participants were designing was in three dimensional space [83]. Despite of this constraint, layering rich bookmarks helped participants to visualize the information and ideate in three dimensional space. For example, participants put rich bookmarks of pillows over a rich bookmark of a sofa to emulate what they would normally arrange these items at home. They resized rich bookmarks so the pillow had the appropriate size on the sofa.

In one session, the male participant shared the same rich bookmarks of a bathroom tile and a wooden floor multiple times to the composition, and arranged them as if he was paving the wall and the floor in his own bathroom at home 4.16 with tiles and wooden floor. All the other rich bookmarks were placed on these tile and floor clippings. He told his partner during the collaboration that doing this help him design.

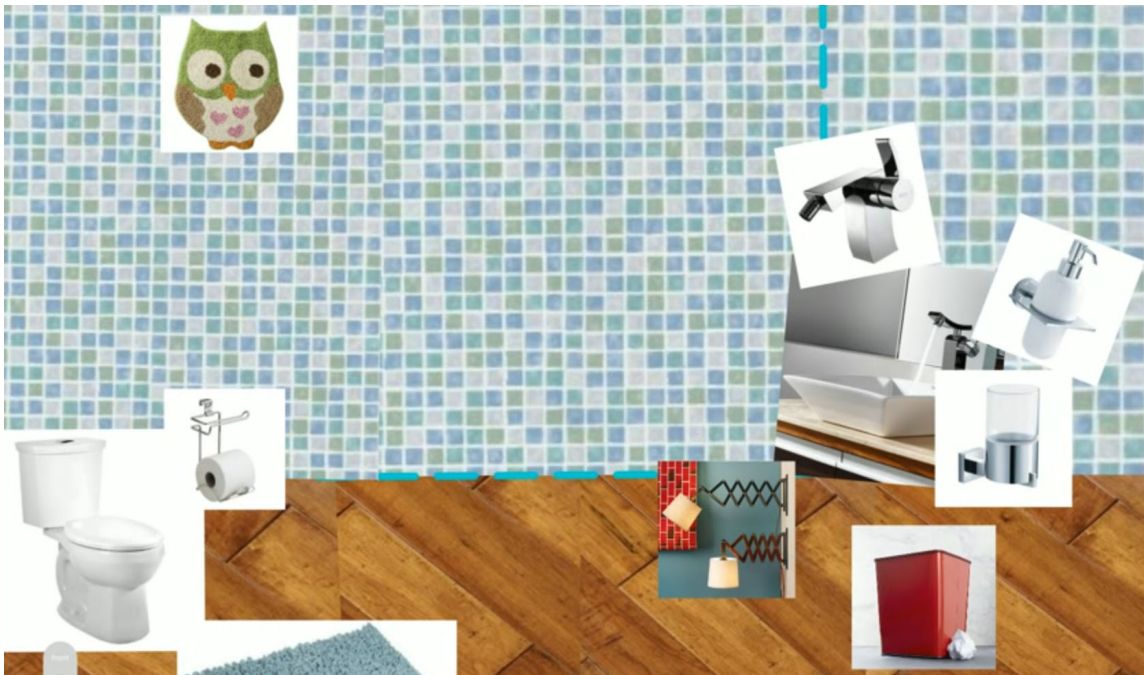


Figure 4.16: Using layering to design the floor, wall, fixtures, and accessories of a bathroom.

In some sessions, even though the layout of an information composition did not directly map to the layout of a room, it still expressed participants' ideas in a meaningful way. Some participants arranged rich bookmarks into category subgroups. Each subgroup contained rich bookmarks with similar or complementary functions

4.4 User Feedback on the Cross-surface Interactive System

In this section, we report on participants' direct feedback regarding components of the cross-surface curation environment. We obtained the feedback from post-study questionnaires and short interviews. They include making connection between the personal and collaborative surface, collecting and sharing rich bookmarks to the collaborative surface, making the joint information composition on the collaborative surface, using the radial menu to delete and share rich bookmarks from the joint information composition, and using the in-context web and metadata browser on rich bookmarks. We asked participants about their habits in conducting similar collaborative ideation tasks at home. We compiled the results in Appendix D.

4.4.1 Making Connection between Personal Surfaces and the Collaborative Surface

Participants found the concept of initiating connection by touching the tablet to an NFC tag intuitive, and easy to use, even though most of the time they only need to make cross-surface connections once. One participant liked the simplicity and quickness of the connecting process compared to the currently time-consuming process of connecting his computer with the television at home. Several participants liked the visual and audio feedback during the connecting process (Section 2.3). They thought the physical motion of touching the tablets with the collaborative surface is novel and fun. One participant said that the embodied connecting process gives him an 'ah ha' moment. However, the different locations of the NFC sensors on the two tablets confused some participants. One participant stated that she did not know which part of the tablet to align with the NFC tag.

Having multiple NFC tag stickers around the rim of the collaborative surface gave each participant freedom to choose the location of her portal on the collaborative surface. Most participants made the connection by touching one of the NFC tags on

the bottom edge of the collaborative surface. One participant touched a tag on the left edge.

4.4.2 Gathering and Sharing Rich Bookmarks to the Collaborative Surface

Participants liked the being able to use the personal surface to browse the Web and collect information. They experienced that this gave them freedom in the collaboration. However, a few had mixed feelings about using tablets in the study. Some participants found it easy to handle the tablet and share its screen to their partners. Participants could hold the tablet in one hand, requiring much less physical strength than a laptop computer, providing a more comfortable, relaxing, and enjoyable experience.

Problems with the tablets came from the size of their display and their performance. A few participants thought that the tablet was too small to browse the web, especially for those websites that were not designed for browsing on a tablet. The web browser on the tablet was also slower than those on many computers.

Participants described the ‘flicking across’ gesture to share rich bookmarks from the tablets to the collaborative surface to be ‘easy’, ‘intuitive’, and ‘natural’. One participant thought the flicking across gesture was what the entire project made a great experience for him. One participant thought that the gesture is ‘intuitive and physical’, but he raised concern that it might not suit the situation when a user wanted to share a clipping to a composition located in another room. However, our design was to intended only to support co-located collaboration. We incorporated embodiment to the sharing process so that the movement of the user’s finger / arm when performing the sharing gesture runs along the relative spatial relationship between the source (tablet) and the target (collaborative surface). Additional design considerations are needed for sharing in other conditions.

Some implementation problems arose from limitations in the Android SDK. Several participants noticed that clicking the menu in the Chrome browser before sharing slowed down the entire sharing process. When they learned the sharing gesture (holding the image, and flicking across), they tended to use it directly in the Chrome browser. When the intended result did not appear, they then realized that they had to use the Chrome’s sharing menu to go to the sharing mode. As we described in the previous chapter, we took this approach in response to performance problems with the WebView component of the Android SDK. We can switch to more direct sharing when Google addresses this.

4.4.3 Creating a Joint Information Composition on the Collaborative Surface

Participants enjoyed creating a joint information composition on the collaborative surface. They quickly learned the familiar multi-touch gestures to move, rotate, and resize rich bookmarks. Participants liked the flexibility of the information composition. The information composition allowed participants to easily visualize the layout, explore alternative possibilities, look at color combinations, and compare items side by side. Participants liked the large size of the collaborative surface, which allowed them to easily see and manipulate information. Some also found it difficult to reach rich bookmarks on the collaborative surface that were away from them.

While some participants used the composition as a layout tool, others simply used it as a collage or a space to place their curation. Some participants enjoyed the flexibility they have with the composition. A composition often went through the messy stages before it emerged as a meaningful product for its designers. One who didn’t pay much attention to the layout said, “At first, the composition on the collaborative surface seemed repetitive and not appealing. The end result made the process more satisfying to see the project come together.”

Cross-surface interaction brought sharing of individual efforts to collaborative information composition. Sharing rich bookmarks granted participants' partners instant access to ideas, and triggered discussion. One participant found it appealing to share rich bookmarks to the joint information composition, because it help him discuss ideas and issues with his partner face to face. Participants also thought making a composition by putting things together and then discussing them streamlined the design process, "It was nice to have everything in front of us and see it (like if you would have a bunch of magazine clippings) and not have to fool with a millions tabs and opening and closing them and webpages loading slow. "

Collaborative information composition also supported participants in articulating and explaining their ideas. One participant said, "I think we discussed what we where doing more efficiently because we could interact directly with what we where doing as well as the concept we were trying to take care of." Collaborative information composition facilitated expressing ideas visually. One participant said, "I could make the photo very big. That, in itself, spoke a lot from my mind. "

Participants also provided suggestions for the system. They wanted to crop out the white background of an image; flip an image; change the background color of the composition; and duplicate the rich bookmark; add inertia to the translation so that they could 'flick' it to move the rich bookmark. One participant criticized the information composition's lack of 'affection' because she could not tangibly hold rich bookmarks and feel them, as with the physical objects that they represent.

4.4.4 Using In-context Metadata and Web Browsers

Participants thought the metadata was useful for quickly getting information and comparing items. Price information in the metadata helped them plan purchases in reference to a budget. In one session, after one participant set a budget for the

entire room, both participants went through the metadata of the products in the composition and summed the total price. Some participants said that although the metadata might not be immediately useful if they already read the information when they collected rich bookmarks, it might be useful if they want to know more about rich bookmarks collected by their partners, or when they went back to rich bookmarks collected long time ago. These feedbacks were consistent with the MICE interface for browsing metadata in exploratory search tasks in a browser in a previous study [84]. MICE displays metadata extracted from the same BigSemantics service used by this study. MICE provides concise summary of the Web pages, reduces the unnecessary noise on the pages. It facilitates tasks involving quick scanning, filtering and comparison of multiple items.

Those participants that did not like the metadata browser complained about the space it took over the composition, making things more crowded. Participants that did not use it much admitted that they consider the aesthetic properties of the design objects, more than price and specifications.

The in-context web browser provided a medium for both participants to browse together on the collaborative surface. Many participants used it similarly to how they would browse together in front of a computer. A difference is that the cross-surface information composition environment concurrently gave them both affordances to scroll and navigate in the browser. Some participants, particularly older ones, also liked it because they found it easier to see the web pages in the physically larger in-context browser than the smaller tablet browser.

5. DISCUSSION

5.1 An Engaging Study Design

A user study is essential to evaluate the efficacy of a novel user interface. Two basic aspects contributed to the success of a user study: a task that engages participants, and a study environment that is ideal to perform the task.

Tasks in many previous multi-touch collaboration studies were academic or business oriented (i.e. [53, 55, 73]). Participants in these studies were usually students or colleagues. A problem with these tasks is that they were not well grounded in participants' actual needs. Therefore, it was hard to provide participants sufficient motivation.

Some studies had better tasks that focused on actual needs of participants. They were family or daily-life oriented, such as trip planning [73, 29] and gift shopping [29]. Participants in these types of studies were couples or friends. However, participants only spent a comparatively short time (i.e. mean 8 minutes in [29]) to finish these tasks. These tasks were not complex enough to engage participants and lead them into deeper discussions.

Our participants were couples with a romantic relationship of various lengths, in different age groups. Our task was important to both participants, since they were working together to design their own shared living space. The task was meaningful to them because they needed to plan a home makeover project. We observed signs of high level of engagement among participants during our study. There was no time limit to finish our study task. Participants invested significant time to finish their designs, over an hour on average. After the session, some participants said that they could do this all night if they did not have to leave for home. Some participants took

pictures of the information compositions to ‘save’ their work, or asked us to send them the result.

In our task, participants gathered rich bookmarks independently on the personal mobile surface, and then share them to the collaborative surface to make a joint information composition. The task could not be easily obtained by divide-and-conquer. They required discussion, negotiation, and debate. Both participants in each romantic couple invested their thoughts and ideas in the task.

In addition to the engaging task, our study setting was also ideal for participants to immerse themselves in the task. Even though it took more time and effort to remodel a lab office into a ‘living-room’ lab, it was well worth the work. Participants were told at the beginning of the study that other people were watching them during the study, but they rarely displayed discomfort. They were not afraid of making fun of their partners or participating in serious debate. The *living-room lab* is a cost effective set up for conducting family oriented studies, as compared to a full ‘living laboratory’ [30]. It has the benefit of allowing participants to immerse themselves in the study, without the need to build a whole house and ask participants to live inside. The ‘living-room’ lab is also more desirable than a basic lab setting for a complex intimate collaborative task, since participants remain comfortable for an extended period.

5.2 An Expressive System for Collaborative Ideation

The embodied cross-surface curation environment enhanced engagement in expressive collaborative ideation. While previous studies proposed to use the interactive tabletop and mobile devices for collaborative ideation [29, 53, 55, 73], our design is distinctive. In our curation environment, users gather information on their personal devices. Among the benefits are that all participants have input controls at

all times, and so can be more independent. They are less likely to be dominated by their partners because they engage in parallel work, instead of searching together on single display groupware. It also has shortcomings, in that the mobile web browser is still inferior to the desktop web browser in terms of performance and display size. We expect that these shortcomings will be overcome as the highly competitive tablet market moves forward. Gathered information are stored and shared as rich bookmarks across platform. Rich bookmarks provide consistent, concise, rich representation of information, and afford re-finding. We also provide intuitive, embodied cross-surface information sharing gestures. The whole touch-enabled big screen collaborative surface is a joint information composition canvas. It serves as a place to hold and build ideas. It emphasizes freeform spatial organization of curated rich bookmarks and expression. It stimulates forming relationships of curated ideas, and generating new ideas.

5.2.1 Engaging Embodied Cross-surface Interaction

Our cross-surface interaction technique leverages Heidegger's concept of engaged familiarity (See Section 1.4). We provide an embodied sharing gesture to transfer information across devices. The sharing gesture mimics the way people share physical objects in terms of the spatial relationships between the devices and the movements of the human bodies. The technique allows seamless switching between work on mobile device and collaborative surface during collaboration. On the collaborative surface, users manipulate information in the form of rich bookmark using touch gestures similar to the way they deal with physical objects. The technique is easy to learn and intuitive to use. It affords natural forms of communication between users while they are interacting with computing devices.

Participants desired the ability to transfer information between devices. As one

participant mentioned, *“Right now we either share an iPad, or switch between two iPads or laptops or computer. There’s no real-time collaboration that this system allows.”* The design of the cross-surface portal and the ‘flicking across’ gesture embodies the sharing experiences to the users. As one user said, *“When you are excited about a thing (that you find on your tablet), and you can just touch it and throw it up there (to the composition), it feels like you are handling the thing that you really like. You feel more ownership over it. It’s a little bit like an endorphins rush. It’s a little bit like what people feel like when they pin something on Pinterest, but it’s even better, because I can grab it, and take it from my own and put it there to show it to him (my partner). It is really cool, what happens is your whole body gets into it. You get kind of a rush. And you get into the composition even more. It’s almost like being in a store, being able to handle tiles. ”*

The embodiment is brought by the combination of the gesture and interaction targets, rich bookmarks. Rich bookmarks contain the image representation of the information object, and its metadata. Sharing rich bookmarks across devices carries more meaning than sharing a file or image. When sharing rich bookmarks, participants perceive that they are passing over a thing, either a tile, a rug, or a piece of furniture. On the information composition, participants are not rotating, zooming, or moving an image (much like what they would do on their smartphone), but rather the tile, the rug, the piece of furniture. Although with its limitation (reduced dimension of a 3D object), our technique empowers the users in other ways. For instance, participants frequently shared rich bookmarks while they were sitting or standing away from the collaborative surface. And they could research on the shared rich bookmarks directly via in-context metadata and web browser.

5.2.2 Information Composition: An Expressive Design Medium

Compared to tools with fixed layout, the information composition provided the users with a more natural, flexible and engaging design medium. One participant compared it to Pinterest, *“Usually I find fully designed images on Pinterest or blogs, and pin them, but rarely do we go back and forth like we did with this system to pinpoint exactly what we like and don’t like about specific images.”* Making a composition using collected information from the Internet made the design process more interactive, manageable and the result more visible. As one participant compared it with browsing on a computer, *“We were able to discuss the rug and shower curtain combination so efficiently and visualize it immediately rather than flipping between web pages.”* Because they were able to manipulate rich bookmarks during the discussion, participants found our system to be more efficient. As one participant said, *“The rate at which we could make changes in our design was much faster than the usual tools we use, such that our design could change at about the same speed as the conversation driving those changes.”*

Much as what was found in the previous study on information composition [9], rich bookmarks in the information composition are not only used to represent actual objects, they often contain much more profound meanings. Our findings from this study prove the previous ones, and provide insights on how they apply on the collaborative ideation tasks. In this study, rich bookmarks served as the reference point, set the theme of the design, and as an inspiration to participants. They helped participants express and articulate ideas to their partners. While previous studies focused on the ideas expressed through the finished information composition, in this study, by observing the whole design process, we found how participants constantly expressed their ideas during the design using information composition.

Participants used rich bookmarks and information composition to do the talking for them. Manipulating rich bookmarks, like zooming and layering, expressed meanings. Changing the visual relationships of rich bookmarks in the composition, like grouping rich bookmarks, helped participants store, organize, and sift their design ideas. Making composition with shared rich bookmarks helped participants in the ideation process by stimulating their creative thinking via reflection-in-action. For instance, participants said, *“My impression was that he understood my reasoning but it wasn’t until I added the picture that he ‘got it’.* ” and *“It was much easier to get his opinion on things beyond ‘I like that’ or ‘I don’t like that’. I got a good sense of his vision for our home.”* Rich bookmarks shared by one participant stimulated the other’s creativity, resulting in emergent ideas: *“We were able to post pictures of something that we liked, and then the other person was able to go off of that idea and enhance it with something that worked for them as well. ”*

5.3 Flexible Face-to-face Collaboration

The cross-surface rich bookmark sharing gesture did not take users’ attention away from the task at hand. After an initial learning period, participants gave their attention to the task and communication with their partners. They have conversations as they otherwise did in their daily lives. They talked about their families and friends. They made jokes and shared funny items to the information composition to amuse their partners. At other times, participants argued with their partners on the design and defended their ideas. In some sessions, participants took care of their babies throughout the study while performing the task. We think that technology is at its best when it empowers users without their noticing its presence. In our study, the technology blended into the background when participants immersed themselves in the task.

5.3.1 Flexible Formations

In previous studies, many collaborative systems with a shared collaborative surface often required participants to stay close and maintain a certain f-formation close to one single display [55, 73, 29]. However, Jakobsen *et al.* [85] found that different groups prefer different physical arrangement before a wall display. Some groups stay in close proximity to each other most of the time, while other groups like to work on different areas of the display. Marshall *et al.* [17] also found that users often change their group arrangement around a tabletop. A confined display space work well for tightly coupled collaboration [86]. When the task requires both individual and joint work, each participant needs a personal workspace in which to perform individual work. In a single display, participants usually use the part of the display immediately in front of them as personal workspace [87]. However, when the display space is limited, switching between group work and individual work may require more explicit coordination [52].

In ‘CoSearch’, the user who took control of the computer stayed in the center of the group that was close to the monitor, while other users with phones stay father away [55]. In ‘WeSearch’, each user had to stay close at one side of the interactive tabletop [73]. In ‘MobiSurf’ [29], even though the users could use both private mobile devices and the interactive tabletop, sharing information between screens required repeatedly physically touching the devices together, which took ongoing attention and forced users to stay close to the tabletop. Although requiring the users to maintain a certain f-formation for a short period maybe acceptable for simple tasks, the users may not feel comfortable to use these systems for a long period in a complex task such as ours, especially in a casual environment like home.

Rogers and Lindley [88] argued that horizontal display affords better collaborative

interaction than vertical display. In their study, participants sitting close around a horizontal table display, but far away from the wall display. Thus, it required more effort to stand up and move toward the vertical display. However, when the wall display has multi-touch capability, it provides more space for group members to work side-by-side [85]. Horizontal displays may not be suitable for certain types of group work when the orientation of the shared information is important. For instance, the user may either need to move himself to a different location around the tabletop in order to read text shared by others, or to rotate the shared information [86].

Marquardt *et al.* [28] design cross-display interactions supporting different F-formations formed by the co-located participants. They used computer vision to sense the F-formations formed by the users with hand-held mobile devices to afford information sharing across devices. When the collaboration involves a shared digital whiteboard, they considered the whiteboard as a participant so that participants can share information from the mobile devices to the whiteboard.

Our cross-surface information sharing technique also affords flexible formations between users. Our observations reinforced related findings from [28]. The distance and the F-formation between participants vary between the based on the needs during the task. Participants got close to the collaborative surface to actively work on the information composition or stayed away from the collaborative surface to work in parallel on the tablets to collect information. Participants did not have to stay close to the collaborative surface when they are mainly working on information seeking individually. One participant said, *“Being able to zoom in and out to see the objects more clearly to show each other. I was able to view everything from sitting close to the screen, on the futon or standing.”* The tablets enabled participants to work in parallel without explicitly negotiating for space on a shared display.

The form factor of the tablets used in this study made it easy for participants to move it into the focal zone when they were working on the tablets or using the contents on their tablets as the topic of communication. But they moved it out of the focal zone when working on the collaborative surface or engaging in face-to-face communication. The size and the vertical orientation of the collaborative surface allowed participants to see the composition and the rich bookmarks they and their partners shared from a distance. The cross-surface portals enabled users to share rich bookmarks from their personal surfaces to the composition space on the collaborative surface.

5.3.2 *Awareness among Multiple Displays and the Partner*

Mutual awareness between group members is important for collaboration, especially when they have to switch between individual and joint work [43]. Keeping awareness of the partners enabled the users to determine when to initiate discussion or identify opportunities for switching to joint work. Jakobsen *et al.* [85] found that short occasional glances are important for participants to maintain mutual awareness for coordinating work.

While in ‘MobiSurf’ the users were also using mobile devices and tabletop surface, they performed the same task, web browsing, on all screens [29]. In our case, users engaged in information-based ideation through curation. It contained multiple sub-tasks, such as gathering information as rich bookmarks, sharing, and assembling rich bookmarks to create the joint information composition. Being aware of the ongoing situation is an essential part of an organic collaboration, especially for the couples with romantic relationships. Observing what the partner is doing leads to further discussion about the design.

In our study, although the devices were physically disconnected, we provided

consistent embodied interaction across all surfaces. Participants could swiftly shift their attentions among the tablets, the collaborative surface, and their partners. Our technique requires very little physical (body and head) movement for attention shifting. We observed that participants took quick occasional glances frequently and opportunistically. It did not take participants' attention completely away from the task at hand, so participant could continue his previous work immediately after working on something else.

In addition to monitoring, participants kept each other aware during collaboration using various methods. We observed that participants communicating verbally of their intentions and interactions. They asked their partners for help when needed. They also commented on their interactions, which Isenberg *et al.* called “running commentary” [89], to let their partners know what they were doing.

5.3.3 Facilitate Communication

One benefit of A horizontal display for collaboration is that it supports face-to-face arrangement, which is useful for group discussion [86, 90]. Users do not have to turn away from the table to communicate. However, side-by-side arrangement in a group may reduce visual distraction when working independently [86]. Jakobsen *et al.* argued that large wall displays also facilitate communication, allowing group members to share information by turning their head or moving closer [85]. Our set up with the collaborative surface tilted 45 degrees and the form factors of the mobile devices in our cross-surface technique facilitate face-to-face communication too. Besides pointing relevant information on the television, the users can discuss information on the mobile devices by sharing the mobile screen with their partners or looking over the partners shoulder. They can turn sideways to face their partner while keeping peripheral view of the television during discussion.

Being able to work alone on the private devices and then put ideas ‘on the table’ helped the collaboration in multiple aspects. One participant felt that when using the system compare to their previous experience, they *“actually spent more time talking”*. Another participant shared the similar opinion, *“Having the images projected onto a common screen made us acknowledge the other person’s input, and caused a discussion to happen. We do not usually engage in that much discussion over picking items for our home. This was a much more effective system than our usual one (where we pretty much do our own thing without talking about it much).”*

Although participants could not always see directly what their partners were browsing on the tablets, they were aware of what their partners were doing through combined visual and verbal communication. One participant said, *“Because of the size of the screen it was easy to miss what my partner was doing and sort of divide up our tasks. But it didn’t get in the way as long as long as I looked over and since we were talking the whole time. ”*

The collaborative surface further facilitated awareness. Participants mentioned that they immediately noticed the rich bookmarks shared by their partners on the collaborative surface during the collaboration. Sharing rich bookmarks to the collaborative surface made ideas clearly visible to the partners, which also stimulate discussion. Being able to manipulate the rich bookmarks on the collaborative surface made discussion more efficient. As one participant said, *“It was easy for us to work together and it facilitated discussion because we could envision exactly what the other person was thinking with the inspiration being front and center on the screen. ”*

5.4 Balancing Workload during Collaboration

Collaborative home makeover design is a dynamic and creative process. Participants alternated working in parallel on personal surfaces and together on the collaborative surface. They dynamically balance the physical and cognitive load. The ideas from participants diverge and converge multiple times during the collaboration. Working in parallel facilitates divergent thinking, avoiding domination of one participant in the collaboration. Work of one participant often inspires the other. While participants could explore the ideas privately, they are aware of their partners using our interactive system.

Our curation environment gave user equal chance to contribute to the design. In the study, we did not ask each participant to do the same type and amount of work. This was essentially one of the reasons that we collaborate in a task: to complement each other. As mentioned before, participants could perform different sub-tasks to achieve the final goals. In addition, finishing the task did not require participants to follow certain steps. The embodied cross-surface curation environment allowed dynamic load balancing during the collaborative design.

5.4.1 *Dynamic Workload Balancing*

Collaborative curation is a mixed-focus task. In a mixed-focus task, users often shift between loosely coupled work and tightly coupled work. Loosely coupled work has fewer dependencies on the others, whereas tightly coupled work require frequent communication among group members [91]. Tablets accommodate individual information gathering, a loosely coupled form of work in our context, while the large surface accommodates collaborative design and discussion, a tightly coupled work. Our system allows readily switching between these two types of work. While frequent sharing to the composition allows the partner to be aware of the work, working pri-

vately gives a user more freedom to explore her personal interests, immune from her partner's opinion. We observed that participants frequently switched between working privately on tablets and collaboratively on the collaborative surface. Although most participants directly shared the rich bookmarks to the composition, we observed that one participant saved all the rich bookmarks to his personal collection without sharing for an extensive period at the beginning of the design process. He explained, *"I like to go and just grab whatever I like first. Then I put it up there to see if it fits later. I just save them so that I don't have to make the immediate decision whether I like it or not."*

The ability to change formation and shift attention swiftly allowed participants to schedule their work according to their needs, and collaborate in a more flexible way. For example, in one session, participants were taking care of an infant while performing the collaborative design. In the early stage of the session, both participants were working on the tablets and the collaborative surface. However, having to take care of the infant constantly made it inconvenient for the mom to work with the tablet. To solve this problem, she negotiated with her husband, asking him to work more on the tablets to find items, and she would work more on the collaborative surface to arrange the shared rich bookmarks. She said, *"At first, the system did not seem to allow the partner who cared for the child to participate, since the child was distracted by the tablet. However, we adapted to make the system work for us. Together we discussed what item we needed for the room. Then my husband would use the tablet to find said object. We could then both look at the object afterwards on the collaborative surface. Occasionally, I could use the tablet to find an object. The limited use of the tablet was not by limitations from my partner."*

5.4.2 Working in Parallel

Our system encourages working in parallel. Stewart *et al.* argued that working in parallel brings both advantages and disadvantages to collaboration [70]. The users can work more effectively since they do not have to take turns. Working in parallel accommodates the cognitive difference between users. However, it could also be a disadvantage if users have conflicting agendas. Users could also potentially communicate less. In our study, working in parallel brought the benefits of parallel work and stimulated communication.

Being able to divide the task increases efficiency. Participants in our study often worked on different information gathering tasks based on their needs and skills. Like one participant said, *“I was able to contribute more because I could save what I was looking at and then communicate with my partner instead of us both trying to look at the same things.”* Working in parallel also encourages divergent thinking, which reduces the chance that one participant dominated the design. *“Having separate spaces to work in was nice because I didn’t have to worry about wasting her time with my random browsing. Once I found something cool, I could just throw it up then. I could also try to be sneaky and add silly stuff if I wanted.”*

The couples in our study were all involved in intimate romantic relationships. They might know their partners’ taste better than others might, but they still often had different tastes from their partners’. Each user brought different strengths to the collaboration. The results of work from both participants usually converged to a design that both participants were satisfied with through the process of experimenting, negotiating, and compromising.

Putting ideas on the collaborative surface by sharing rich bookmarks stimulates partners’ participation instead of putting them off. As one participant said, *“I felt*

like I could find everything I liked and lay it out for him to see so there was not a lot of overload or over stimulation for him. ” The collaborative surface also improves awareness of during parallel working, like what a participant said, *“Having the images projected onto a common screen made us acknowledge the other person’s input, and caused a discussion to happen. ”*

5.4.3 Equal Participation

It was found that multi-touch input encourages equal participation [39, 53]. Participants are more likely to work in parallel using multi-touch enabled devices than traditional input devices. Our system further encourages equal participation by providing users mobile devices to work in parallel. It reduces the potential of one user dominating the collaboration. Participants in our study appreciated that both partners’ ideas were brought into the design. Each participant could browse the web to collect the information in the way she wanted, and shared to the collaborative surface without restriction. One participant said, *“We were able to be autonomous but also collaborative. We were both able to create and contribute. We both didn’t have to agree to what was in the composition but it was still there.”*

In previous studies, it was found that users often partition the shared display and tend to work on their own personal space, partly to avoid interference [52, 90]. We provided participants with tablets to serve as their personal spaces. We found less partitioning on the shared display. Participants were more open to collaboratively transforming the entire shared display. Once a rich bookmark was shared to the display, both participants could use it. Here are some thoughts from participants: *“We were able to be autonomous but also collaborative. We were both able to create and contribute. We both didn’t have to agree to what was in the composition but it was still there.”*; *“We really were able to talk to each other and discuss what the*

other was seeing because we'd find something and say hey look and jump it up on the screen. I liked that we can both be in charge of our separate ideas then lay them out all on the table (monitor) and discuss from there. ”; “We were both able to add ideas, and thus neither one of us really dominated the design process.”

Although they often worked in parallel, participants engaged in discussion and debate. We found that our participants were not afraid of laying out their ideas by modifying the composition. They generally did not feel intimidated by their partners. This was partly caused by the fact that participants were all couples with intimate relationships. We observed that some participants intentionally interfered with their partners by changing the rich bookmarks together. The information compositions in the end were cohesive combinations of both their and their partners' ideas. Even though the process involved negotiation and compromise. Like participants said, *“My partner's image choice included a lot of modern-looking furniture choices, but he was willing to indulge on color or style that was found in some of the images I posted. ”* Our system made both participants felt that they were engaged, as one participant said, *“We put more effort into the design and probably didn't fight as much because we were not alone.”*

6. CONCLUSIONS

In this study, we developed an embodied cross-surface curating environment that supports collaborative information-based ideation tasks. Our design uses a tilted, touch-enabled collaborative surface for jointly creating information composition, and small tablets for each user to individually curate information from the Web as rich bookmarks and share them to the information composition using the embodied cross-surface information sharing technique. The technique is based on an intuitive gesture based device association technique that uses NFC technology. A user associates a tablet to a position on a collaborative surface by touching the tablet to an NFC tag on the edge of the collaborative surface.

In our environment, rich bookmarks serve as the medium for elements of curation. Rich bookmarks are consistent representation for information across surfaces, facilitating switching between private and collaborative work during collaboration. Collecting rich bookmarks on the personal surface encourages users to bring independent thinking to collaboration. Information composition serves as the medium of assemblage of curated rich bookmarks. Ideas from collaborators collide and evolve through spatially organizing rich bookmarks in compositions.

In our user study, couples with romantic relationship used this environment to design shared living spaces. The observation and feedback from participants indicated that the synergy of the personal surfaces and embodied cross-surface interaction techniques engaged participants. It facilitated natural, face-to-face communication by allowing flexible formations. Participants worked independently on the tablets while still maintain awareness of their partners. Participants dynamically balanced their work loads, switching between independently collecting rich bookmarks on individ-

ual surfaces and jointly designing the information composition on the collaborative surface. The environment encouraged both participants in a group to contribute to the design process. The embodied cross-surface curating environment stimulated creativity in the collaborative information-based ideation task.

REFERENCES

- [1] A. Kerne, A. M. Webb, S. M. Smith, R. Linder, N. Lupfer, Y. Qu, J. Moeller, and S. Damaraju, “Using metrics of curation to evaluate information-based ideation,” *ACM Trans. Comput.-Hum. Interact.*, vol. 21, pp. 14:1–14:48, June 2014.
- [2] S. Rosenbaum, *Curation Nation: How to Win in a World Where Consumers are Creators*. New York City, NY, USA: McGraw-Hill Education, 2011.
- [3] N. Lupfer, “Beyond the feed and board: Holistic principles for expressive web curation,” Master’s thesis, Texas A&M University, 2014.
- [4] “Pinterest.” <http://www.pinterest.com>. Retrieved on November 13, 2014.
- [5] R. Linder, C. Snodgrass, and A. Kerne, “Everyday ideation: All of my ideas are on pinterest,” in *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, CHI ’14, (New York, NY, USA), pp. 2411–2420, ACM, 2014.
- [6] A. Webb, R. Linder, A. Kerne, N. Lupfer, Y. Qu, B. Poffenberger, and C. Revia, “Promoting reflection and interpretation in education: Curating rich bookmarks as information composition,” in *Proceedings of Creativity and Cognition*, (Sydney, Australia), 2013.
- [7] A. M. Glenberg and W. E. Langston, “Comprehension of illustrated text: Pictures help to build mental models,” *Journal of Memory and Language*, vol. 31, no. 2, pp. 129 – 151, 1992.
- [8] J. Teevan, E. Cutrell, D. Fisher, S. M. Drucker, G. Ramos, P. André, and C. Hu, “Visual snippets: summarizing web pages for search and revisitation,” in *Proc*

- CHI*, 2009.
- [9] A. M. Webb and A. Kerne, “Integrating implicit structure visualization with authoring promotes ideation,” in *Proceedings of the 11th annual international ACM/IEEE joint conference on Digital libraries*, JCDL ’11, (New York, NY, USA), pp. 203–212, ACM, 2011.
 - [10] A. Kerne, E. Koh, S. M. Smith, A. Webb, and B. Dworaczyk, “combinformation: Mixed-initiative composition of image and text surrogates promotes information discovery,” *ACM Trans. Inf. Syst.*, vol. 27, pp. 5:1–5:45, Dec. 2008.
 - [11] S. A. Paul and M. R. Morris, “Cosense: enhancing sensemaking for collaborative web search,” in *Proc CHI*, CHI ’09, (New York, NY, USA), pp. 1771–1780, ACM, 2009.
 - [12] M. Weiser, “The computer for the 21st century,” *Scientific American*, vol. 265, no. 3, pp. 94–104, 1991.
 - [13] M. Nacenta, C. Gutwin, D. Aliakseyeu, and S. Subramanian, “There and back again: Cross-display object movement in multi-display environments,” *Journal of Human-Computer Interaction*, vol. 24, no. 1, pp. 170–229, 2009.
 - [14] A. Kerne, W. A. Hamilton, and Z. O. Toups, “Culturally based design: embodying trans-surface interaction in rummy,” in *Proceedings of the ACM 2012 conference on Computer Supported Cooperative Work*, CSCW ’12, pp. 509–518, 2012.
 - [15] Oxford University Press, *The Oxford English Dictionary*. 2013.
 - [16] C. Gutwin, S. Subramanian, and D. Pinelle, “Designing digital tables for highly integrated collaboration,” Tech. Rep. HCI-TR-06-02, 2006.

- [17] P. Marshall, R. Morris, Y. Rogers, S. Kreitmayer, and M. Davies, “Rethinking ‘multi-user’: an in-the-wild study of how groups approach a walk-up-and-use tabletop interface,” in *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, CHI ’11, (New York, NY, USA), pp. 3033–3042, ACM, 2011.
- [18] E. Hornecker and J. Buur, “Getting a grip on tangible interaction: a framework on physical space and social interaction,” in *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, CHI ’06, (New York, NY, USA), pp. 437–446, ACM, 2006.
- [19] A. M. Glenberg and M. P. Kaschak, “Grounding language in action,” *Psychonomic bulletin & review*, vol. 9, no. 3, pp. 558–565, 2002.
- [20] J. V. Nickerson, J. E. Corter, B. Tversky, D. Zahner, and Y. J. Rho, “The spatial nature of thought: understanding systems design through diagrams,” *ICIS 2008 PROCEEDINGS*, 2008.
- [21] A. Glenberg, “Why mental models must be embodied,” in *Mental Models in Discourse Processing and Reasoning* (G. Rickheit and C. Habel, eds.), vol. 128 of *Advances in Psychology*, pp. 77 – 90, North-Holland, 1999.
- [22] J. J. Gibson, “The theory of affordances,” in *Perceiving, Acting, and Knowing* (S. R. E. and B. J., eds.), Mahwah, New Jersey, USA: Lawrence Erlbaum Associates, 1977.
- [23] M. Heidegger, *Being and Time*. New York City, NY, USA: Harper Perennial, 2008.
- [24] G. D. Abowd and E. D. Mynatt, “Charting past, present, and future research in ubiquitous computing,” *ACM Trans. Comput.-Hum. Interact.*, vol. 7, pp. 29–58,

Mar. 2000.

- [25] B. F. Moss and A. I. Schwebel, “Defining intimacy in romantic relationships,” *Family Relations*, vol. 42, no. 1, pp. pp. 31–37, 1993.
- [26] A. Kendon, *Conducting Interaction: Patterns of Behavior in Focused Encounters*. Studies in Interactional Sociolinguistics, Cambridge, UK: Cambridge University Press, 1990.
- [27] A. Kendon, “Spacing and orientation in co-present interaction,” in *Proceedings of the Second International Conference on Development of Multimodal Interfaces: Active Listening and Synchrony*, COST’09, (Berlin, Heidelberg), pp. 1–15, Springer-Verlag, 2010.
- [28] N. Marquardt, K. Hinckley, and S. Greenberg, “Cross-device interaction via micro-mobility and f-formations,” in *Proceedings of the 25th annual ACM symposium on User interface software and technology*, UIST ’12, pp. 13–22, 2012.
- [29] J. Seifert, A. Simeone, D. Schmidt, P. Holleis, C. Reinartz, M. Wagner, H. Gellersen, and E. Rukzio, “Mobisurf: improving co-located collaboration through integrating mobile devices and interactive surfaces,” in *Proceedings of the 2012 ACM international conference on Interactive tabletops and surfaces*, ITS ’12, pp. 51–60, 2012.
- [30] C. D. Kidd, R. Orr, G. D. Abowd, C. G. Atkeson, I. A. Essa, B. MacIntyre, E. D. Mynatt, T. Starner, and W. Newstetter, “The aware home: A living laboratory for ubiquitous computing research,” in *Proceedings of the Second International Workshop on Cooperative Buildings, Integrating Information, Organization, and Architecture*, CoBuild ’99, (London, UK, UK), pp. 191–198, Springer-Verlag, 1999.

- [31] M. R. Morris, “Web on the wall: Insights from a multimodal interaction elicitation study,” in *Proceedings of the 2012 ACM International Conference on Interactive Tabletops and Surfaces*, ITS '12, (New York, NY, USA), pp. 95–104, ACM, 2012.
- [32] A. Kerne, E. Koh, B. Dworaczyk, J. M. Mistrot, H. Choi, S. M. Smith, R. Graeber, D. Caruso, A. Webb, R. Hill, and J. Albea, “combinformation: A mixed-initiative system for representing collections as compositions of image and text surrogates,” in *Proceedings of the 6th ACM/IEEE-CS Joint Conference on Digital Libraries*, JCDL '06, (New York, NY, USA), pp. 11–20, ACM, 2006.
- [33] H. Bruce, W. Jones, and S. Dumais, “Keeping and re-finding information on the web: What do people do and what do they need?,” *Proceedings of the American Society for Information Science and Technology*, vol. 41, no. 1, pp. 129–137, 2004.
- [34] N. W. Kohn and S. M. Smith, “Collaborative fixation: Effects of others’ ideas on brainstorming,” *Applied Cognitive Psychology*, vol. 25, no. 3, pp. 359–371, 2011.
- [35] B. Tognazzini, “First principles of interaction design.” <http://asktog.com/atc/principles-of-interaction-design/>. Retrieved on November 13, 2014.
- [36] S. Fei, A. M. Webb, A. Kerne, Y. Qu, and A. Jain, “Peripheral array of tangible nfc tags: Positioning portals for embodied trans-surface interaction,” in *Proceedings of the 2013 ACM International Conference on Interactive Tabletops and Surfaces*, ITS '13, (New York, NY, USA), pp. 33–36, ACM, 2013.
- [37] E. Hornecker, “Interactions around a contextually embedded system,” in *Proceedings of the fourth international conference on Tangible, embedded, and embodied interaction*, TEI '10, (New York, NY, USA), pp. 169–176, ACM, 2010.

- [38] N. Shahzad, “S.IM.PL serialization: Translation scopes encapsulate cross-platform, multi-format information binding,” Master’s thesis, Texas A&M University, 2011.
- [39] E. Hornecker, P. Marshall, N. S. Dalton, and Y. Rogers, “Collaboration and interference: awareness with mice or touch input,” in *Proceedings of the 2008 ACM conference on Computer supported cooperative work, CSCW ’08*, (New York, NY, USA), pp. 167–176, ACM, 2008.
- [40] R. Fleck, Y. Rogers, N. Yuill, P. Marshall, A. Carr, J. Rick, and V. Bonnett, “Actions speak loudly with words: unpacking collaboration around the table,” in *Proceedings of the ACM International Conference on Interactive Tabletops and Surfaces, ITS ’09*, (New York, NY, USA), pp. 189–196, ACM, 2009.
- [41] Y. Rogers, Y.-K. Lim, and W. R. Hazlewood, “Extending tabletops to support flexible collaborative interactions,” in *Proceedings of the First IEEE International Workshop on Horizontal Interactive Human-Computer Systems, TABLETOP ’06*, (Washington, DC, USA), pp. 71–78, IEEE Computer Society, 2006.
- [42] A. Harris, J. Rick, V. Bonnett, N. Yuill, R. Fleck, P. Marshall, and Y. Rogers, “Around the table: are multiple-touch surfaces better than single-touch for children’s collaborative interactions?,” in *Proceedings of the 9th international conference on Computer supported collaborative learning - Volume 1, CSCL’09*, pp. 335–344, International Society of the Learning Sciences, 2009.
- [43] C. Gutwin and S. Greenberg, “A descriptive framework of workspace awareness for real-time groupware,” *Comput. Supported Coop. Work*, vol. 11, pp. 411–446, Nov. 2002.
- [44] K. Ryall, A. Esenther, K. Everitt, C. Forlines, M. R. Morris, C. Shen, S. Shipman, and F. Vernier, “idwidgets: parameterizing widgets by user identity,”

- in *Proceedings of the 2005 IFIP TC13 international conference on Human-Computer Interaction*, INTERACT'05, (Berlin, Heidelberg), pp. 1124–1128, Springer-Verlag, 2005.
- [45] S. Bateman, C. Gutwin, G. McCalla, and R. White, “Collective information seeking: Supporting search with low-cost activity sharing and collaboration,” in *The Workshop on Human-Computer Interaction in Information Retrieval (HCIR 2011)*, (Mountain View, CA), p. 4 pages, 2011.
- [46] D. Pinelle, C. Gutwin, and M. Nacenta, “The effects of co-present embodiments on awareness and collaboration in tabletop groupware,” in *Proceeding of Graphics Interface (GI 2008)*, 2008.
- [47] P. Peltonen, E. Kurvinen, A. Salovaara, G. Jacucci, T. Ilmonen, J. Evans, A. Oulasvirta, and P. Saarikko, “It’s mine, don’t touch!: interactions at a large multi-touch display in a city centre,” in *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, CHI '08, (New York, NY, USA), pp. 1285–1294, ACM, 2008.
- [48] M. R. Morris, K. Ryall, C. Shen, C. Forlines, and F. Vernier, “Beyond “social protocols”: multi-user coordination policies for co-located groupware,” in *Proceedings of the 2004 ACM conference on Computer supported cooperative work*, CSCW '04, (New York, NY, USA), pp. 262–265, ACM, 2004.
- [49] D. Pinelle, M. Barjawi, M. Nacenta, and R. Mandryk, “An evaluation of coordination techniques for protecting objects and territories in tabletop groupware,” in *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, CHI '09, (New York, NY, USA), pp. 2129–2138, ACM, 2009.
- [50] S. D. Scott, “Territory-based interaction techniques for tabletop collaboration,” in *Conference Companion of the ACM Symposium on User Interface Software*

- and Technology*, UIST '03, 2003.
- [51] S. D. Scott, K. D. Grant, and R. L. Mandryk, “System guidelines for co-located, collaborative work on a tabletop display,” in *Proceedings of the eighth conference on European Conference on Computer Supported Cooperative Work*, EC-SCW'03, (Norwell, MA, USA), pp. 159–178, Kluwer Academic Publishers, 2003.
- [52] S. D. Scott, M. Sheelagh, T. Carpendale, and K. M. Inkpen, “Territoriality in collaborative tabletop workspaces,” in *Proceedings of the 2004 ACM conference on Computer supported cooperative work*, CSCW '04, (New York, NY, USA), pp. 294–303, ACM, 2004.
- [53] P. Marshall, E. Hornecker, R. Morris, N. S. Dalton, and Y. Rogers, “When the fingers do the talking: A study of group participation with varying constraints to a tabletop interface,” in *Horizontal Interactive Human Computer Systems, 2008. TABLETOP 2008. 3rd IEEE International Workshop on*, pp. 33–40, 2008.
- [54] Y. Rogers, Y.-k. Lim, W. R. Hazlewood, and P. Marshall, “Equal opportunities: Do shareable interfaces promote more group participation than single user displays?,” *Human-Computer Interaction*, vol. 24, no. 1-2, pp. 79–116, 2009.
- [55] S. Amershi and M. R. Morris, “Cosearch: a system for co-located collaborative web search,” in *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, CHI '08, pp. 1647–1656, 2008.
- [56] T. Coughlan, T. D. Collins, A. Adams, Y. Rogers, P. A. Haya, and E. Martn, “The conceptual framing, design and evaluation of device ecologies for collaborative activities,” *International Journal of Human-Computer Studies*, vol. 70, no. 10, pp. 765 – 779, 2012. Special issue on Developing, Evaluating and Deploying Multi-touch Systems.

- [57] S. N. Patel, J. S. Pierce, and G. D. Abowd, “A gesture-based authentication scheme for untrusted public terminals,” in *Proceedings of the 17th annual ACM symposium on User interface software and technology*, UIST '04, (New York, NY, USA), pp. 157–160, ACM, 2004.
- [58] R. Ballagas, M. Rohs, and J. G. Sheridan, “Sweep and point and shoot: phonecam-based interactions for large public displays,” in *CHI '05 Extended Abstracts on Human Factors in Computing Systems*, CHI EA '05, (New York, NY, USA), pp. 1200–1203, ACM, 2005.
- [59] G. Ramos, K. Hinckley, A. Wilson, and R. Sarin, “Synchronous gestures in multi-display environments,” *Humanomputer Interaction*, vol. 24, no. 1-2, pp. 117–169, 2009.
- [60] K. Hinckley, G. Ramos, F. Guimbretiere, P. Baudisch, and M. Smith, “Stitching: pen gestures that span multiple displays,” in *Proceedings of the working conference on Advanced visual interfaces*, AVI '04, (New York, NY, USA), pp. 23–31, ACM, 2004.
- [61] D. Schmidt, F. Chehimi, E. Rukzio, and H. Gellersen, “Phonetouch: a technique for direct phone interaction on surfaces,” in *Proceedings of the 23rd annual ACM symposium on User interface software and technology*, UIST '10, pp. 13–16, 2010.
- [62] A. D. Wilson and R. Sarin, “Bluetable: connecting wireless mobile devices on interactive surfaces using vision-based handshaking,” in *Proceedings of Graphics Interface 2007*, GI '07, pp. 119–125, 2007.
- [63] T. Pering, R. Ballagas, and R. Want, “Spontaneous marriages of mobile devices and interactive spaces,” *Commun. ACM*, vol. 48, pp. 53–59, Sept. 2005.

- [64] M. Sugimoto, K. Hosoi, and H. Hashizume, “Caretta: a system for supporting face-to-face collaboration by integrating personal and shared spaces,” in *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, CHI '04, pp. 41–48, 2004.
- [65] K. Seewoonauth, E. Rukzio, R. Hardy, and P. Holleis, “Two nfc interaction techniques for quickly exchanging pictures between a mobile phone and a computer,” in *Proceedings of the 11th International Conference on Human-Computer Interaction with Mobile Devices and Services*, MobileHCI '09, pp. 39:1–39:4, 2009.
- [66] J. Rekimoto, “Pick-and-drop: a direct manipulation technique for multiple computer environments,” in *Proceedings of the 10th annual ACM symposium on User interface software and technology*, UIST '97, (New York, NY, USA), pp. 31–39, ACM, 1997.
- [67] M. Wu and R. Balakrishnan, “Multi-finger and whole hand gestural interaction techniques for multi-user tabletop displays,” in *Proceedings of the 16th annual ACM symposium on User interface software and technology*, UIST '03, (New York, NY, USA), pp. 193–202, ACM, 2003.
- [68] “Android beam.” <http://developer.android.com/guide/topics/connectivity/nfc/>. Retrieved on November 13, 2014.
- [69] B. Dodson and M. S. Lam, “Micro-interactions with nfc-enabled mobile phones,” in *Mobile Computing, Applications, and Services* (J. Zhang, J. Wilkiewicz, and A. Nahapetian, eds.), vol. 95 of *Lecture Notes of the Institute for Computer Sciences, Social Informatics and Telecommunications Engineering*, pp. 118–136, Springer Berlin Heidelberg, 2012.
- [70] J. Stewart, B. B. Bederson, and A. Druin, “Single display groupware: a model for co-present collaboration,” in *Proceedings of the SIGCHI conference on Human*

- Factors in Computing Systems*, CHI '99, (New York, NY, USA), pp. 286–293, ACM, 1999.
- [71] C. Shen, N. B. Lesh, F. Vernier, C. Forlines, and J. Frost, “Sharing and building digital group histories,” in *Proceedings of the 2002 ACM conference on Computer supported cooperative work*, CSCW '02, (New York, NY, USA), pp. 324–333, ACM, 2002.
- [72] M. R. Morris and J. Teevan, “Collaborative web search: Who, what, where, when, and why,” *Synthesis Lectures on Information Concepts, Retrieval, and Services*, vol. 1, no. 1, pp. 1–99, 2009.
- [73] M. R. Morris, J. Lombardo, and D. Wigdor, “Wesearch: supporting collaborative search and sensemaking on a tabletop display,” in *Proceedings of the 2010 ACM conference on Computer supported cooperative work*, CSCW '10, (New York, NY, USA), pp. 401–410, ACM, 2010.
- [74] J. R. Wallace, S. D. Scott, and C. G. MacGregor, “Collaborative sensemaking on a digital tabletop and personal tablets: prioritization, comparisons, and tableaux,” in *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, CHI '13, (New York, NY, USA), pp. 3345–3354, ACM, 2013.
- [75] J. P. Guilford, “The structure of intellect,” *Psychological Bulletin*, vol. 53, pp. 267–293, 1956.
- [76] S. M. Smith, T. B. Ward, and R. A. Finke, *The Creative Cognition Approach*. Cambridge, Massachusetts, USA: MIT Press, 1995.
- [77] J. J. Shah, S. M. Smith, and N. Vargas-Hernandez, “Metrics for measuring ideation effectiveness,” *Design Studies*, vol. 24, no. 2, pp. 111 – 134, 2003.

- [78] A. Kerne, S. M. Smith, E. Koh, H. Choi, and R. Graeber, “An experimental method for measuring the emergence of new ideas in information discovery,” *International Journal of Human-Computer Interaction*, vol. 24, no. 5, pp. 460–477, 2008.
- [79] “Open broadcaster software.” <https://obsproject.com/>. Retrieved on November 13, 2014.
- [80] K. Charmaz, *Constructing Grounded Theory: A Practical Guide Through Qualitative Analysis*. Introducing Qualitative Methods series, Thousand Oaks, CA, USA: SAGE Publications, 2006.
- [81] N. Yuill and Y. Rogers, “Mechanisms for collaboration: A design and evaluation framework for multi-user interfaces,” *ACM Trans. Comput.-Hum. Interact.*, vol. 19, pp. 1:1–1:25, May 2012.
- [82] A. Kerne, E. Koh, S. Smith, H. Choi, R. Graeber, and A. Webb, “Promoting emergence in information discovery by representing collections with composition,” in *Proceedings of the 6th ACM SIGCHI Conference on Creativity & Cognition, C&C '07*, (New York, NY, USA), pp. 117–126, ACM, 2007.
- [83] E. R. Tufte, *Envisioning Information*. Cheshire, CT, USA: Graphics Press, 2001.
- [84] Y. Qu, A. Kerne, N. Lupfer, R. Linder, and A. Jain, “Metadata type system: Integrate presentation, data models and extraction to enable exploratory browsing interfaces,” in *Proceedings of the 2014 ACM SIGCHI Symposium on Engineering Interactive Computing Systems, EICS '14*, (New York, NY, USA), pp. 107–116, ACM, 2014.

- [85] M. R. Jakobsen and K. Hornbæk, “Up close and personal: Collaborative work on a high-resolution multitouch wall display,” *ACM Trans. Comput.-Hum. Interact.*, vol. 21, pp. 11:1–11:34, Feb. 2014.
- [86] A. Tang, M. Tory, B. Po, P. Neumann, and S. Carpendale, “Collaborative coupling over tabletop displays,” in *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, CHI ’06, (New York, NY, USA), pp. 1181–1190, ACM, 2006.
- [87] R. Kruger, S. Carpendale, S. D. Scott, and S. Greenberg, “Roles of orientation in tabletop collaboration: Comprehension, coordination and communication,” *Comput. Supported Coop. Work*, vol. 13, pp. 501–537, Dec. 2004.
- [88] Y. Rogers and S. Lindley, “Collaborating around vertical and horizontal large interactive displays: which way is best?,” *Interacting with Computers*, vol. 16, no. 6, pp. 1133 – 1152, 2004.
- [89] P. Isenberg, A. Bezerianos, N. Henry, S. Carpendale, and J.-D. Fekete, “Coconutrix: Collaborative retrofitting for information visualization,” *IEEE Comput. Graph. Appl.*, vol. 29, pp. 44–57, Sept. 2009.
- [90] P. Isenberg, D. Fisher, S. A. Paul, M. Ringel Morris, K. Inkpen, and M. Czerwinski, “Co-located collaborative visual analytics around a tabletop display,” *IEEE Transactions on Visualization and Computer Graphics*, vol. 18, pp. 689–702, May 2012.
- [91] G. M. Olson and J. S. Olson, “Distance matters,” *Hum.-Comput. Interact.*, vol. 15, pp. 139–178, Sept. 2000.
- [92] A. Kerne, Y. Qu, S. Damaraju, N. Lupfer, and A. Mathur, “Meta-metadata: a metadata semantics language for collection representation applications,” in

Proc ACM Conference on Information and Knowledge Management, 2010.

- [93] Z. O. Toups, A. Kerne, W. A. Hamilton, and N. Shahzad, “Object-oriented distributed semantic services: A s.im.pl approach,” tech. rep., 2010.

APPENDIX A

RICH BOOKMARK REPRESENTATION AND BIGSEMANTICS SERVICE

BigSemantics Service extracts metadata from the webpage based on meta-metadata language and architecture [92]. The underlying serialization and deserialization mechanisms of S.IM.PL (Support for Information Mapping in Programming Languages) [38] facilitate storing instances of resulting metadata subclasses, and transmitting these through network connections. The BigSemantics Service derives metadata from a large amount of heterogeneous information sources because it uses the community curated meta-metadata declarations.

Meta-metadata type system allows describing the structure of metadata using S.IM.PL basic types: scalar, composite, and collection which are mapped to Java types. Meta-metadata types include data model, in the form of metadata subclasses, as well as extraction rules for deriving instances of metadata for particular information sources, and presentation rules that structure what the user sees. Curators use meta-metadata to declare metadata types for information sources. The inheritance mechanisms of the meta-metadata type system enable defining meta-metadata types using previously defined types as building blocks. The polymorphism of resulting metadata subclasses facilitates performing common operations on different types corresponding to the data models for heterogeneous information sources. S.IM.PL type system scope binds the meta-metadata type system to guarantee correct serialization and deserialization to and from a metadata object. During serialization, the type system scope iterates through a metadata object recursively to get metadata information for serializing each scalar element. During deserialization, the type system scope builds an equivalent object model as the serialized metadata by finding

the corresponding metadata subclasses for each data node, and then maps the data to the object.

To generate a metadata object, mobile application sends URL of the web page as the parameter of a GET request to the BigSemantics Service. The Server looks up the meta-metadata type in its repository for the particular information source according to mime type and URL pattern of the web page. Based on the meta-metadata type, the type system scope instantiates a corresponding metadata subtype object. Metadata are extracted from HTML or XML information resources, based on XPath and regular expressions defined in the metadata type declaration. The type system scope then performs a depth-first traversal of the metadata data structures to populate the metadata object.

Metadata polymorphism in combination with the binding of meta-metadata descriptors to each metadata subclass and each of its fields enable authoring a generic metadata presentation widget that lets the user expand / collapse / browse instance of metadata subclasses of any complexity. Meta-information in the metadata declaration specifies presentation rules of metadata, whether a metadata field should be shown, whether a user can navigate to a link by interacting with the field, and in what order the fields in the metadata will be show. Once the application defines generic metadata presentation methods, they work for metadata types for each information source. In our study, the mobile application and the collaborative application both define their own metadata presentation methods to present metadata in different metadata viewers.

The serialization and deserialization mechanisms of S.IM.PL enable cross-surface rich bookmark exchange. When the cross-surface server, IdeaMÂCHÉ mobile application and EmbodiedMÂCHÉ application on collaborative surface start, they either request the meta-metadata repository from the BigSemantics service or load it from

the jar file (in the case of mobile application). The type system scope makes sure that a serialized rich bookmark on the sender will be deserialized to the exactly same rich bookmark object, with the correct meta-metadata, on the receiving side. They also enable saving and restoring the rich bookmark collection on the mobile devices as well as the composition on the collaborative surface.

APPENDIX B

NFC TAGS

B.1 NFC Tag Design

We initially used white circle shaped NFC stickers. Although the shape and size of these NFC stickers fit well on the ZeroTouch around the TV, we met several problems later. The size and the position of the NFC sensor on the mobile devices that read the tags vary from device to device. In order to successfully detect an NFC sticker, the antenna of NFC sensor has to be directly above the NFC tag. From users' perspective, the ideal location of the NFC antenna would be close to the top edge of the mobile device. However, the device designers and manufacturers do not follow a certain rule. Thus, the bigger the circuit on the NFC tag, the easier for a mobile device's NFC sensor to detect the tag. The tags in the white round NFC stickers we used before were too small for different mobile devices to consistently detect them.

We also want the NFC stickers to serve as an entry point for cross-surface interaction. Thus, we want to make the affordance more obvious and appealing to the users. So later, we chose to use a PVC NFC card with the size of a business card, and designed the artwork of the front side of the card (Figure 2.7).

B.2 NFC Tag Specification and Data Structure

In our initial implementation, we used the circle NFC sticker with MIFARE Ultralight tags, each containing 64 bytes of memory (48 bytes writable). In later implementation, we used customized NFC PVC card with Topaz tag. which contains 512 bytes of memory. Each tag can store multiple NDEF messages. Each NDEF message contains a MIME type and a payload. The actual data used for cross-surface

portal initialization are stored as one payload in the NDEF message.

Table B.1 lists the payload schema of the NDEF message we store on each tag.

Table B.1: Payload schema of the NDEF message on NFC tags

Sec.	Len. (byte)	Description
0	2	X Position, Y Position
1	2	Number of tags along X, and along Y
2	4	IPv4 address
3	2	Port number
4	1	Length of the SSID section
5	variable	SSID of the SoftAP Wi-Fi network
6	1	Length of the password section
7	variable	Password of the Wi-Fi network

In order to reduce the size of the message to fit on the MIFARE Ultralight tag memory, we don't serialize the descriptions of the fields. Taking the 55" inch television as an example, we divide the display into a 2D grid. Assuming the television is horizontally placed, and we are close to the bottom edge of the television. We set the top left corner of the television as the origin, the shorter edge as X-axis, and the longer edge as Y-axis. We don't place tags on the corners of the television, so the number of tags along X-axis is 6, and number of tags along Y-axis is 3.

Section 2 and 3 contain the IPv4 address and the port number of the WebSocket Server. They are used for the client application to connect to the WebSocket Server. Each portion of the IPv4 address is a value between 0-255, and represented in binary form in a single byte. The port number is a value between 0-65535 represented in binary form in two bytes.

Section 4 and 5 contains the SSID (service set identifier) of the ad hoc Wi-Fi

network that the clients need to connect to first in order to login to the WebSocket Server. The length of section 5 is variable based on the length of the SSID name, which is a value between 1 and 32, since the SSID has to be between 1 to 32 byte long. The length is stored in section 4 in one byte. Similarly, section 6 and 7 store the password of the Wi-Fi network. Different security type of Wi-Fi network requires different length of the password. According to WPA protocol, the shared password should be between 8 to 63 printable ASCII characters. Since there are limits on the tag memory size, there are also hard limits on the length of the SSID and password that can be used. The MIFARE Ultralight tags can be replaced with other type of NFC tags that contain larger memories in practice. Serialize the password directly onto a readable memory may raise security concern, especially in public settings. In practice we encrypt the password and put the decode method in the client application, so that only the verified applications can connect to the Wi-Fi and the WebSocket Server.

B.3 Read/Write the NDEF Message on an NFC Tag

The Android system contains a complete stack for reading and writing NDEF messages on NFC tags. We developed an Android application *NFC_TagWriter* to easily read and write the data structure we designed for our system.

When *NFC_TagWriter* is running on an Android device with NFC support, a user can touch the NFC tag with the android device. If the tag is already programmed with the NDEF message that contains the payload following the specified data structure for our application, the application will parse the data and display the information. User can also change the parameters for each field of the settings and write the new data into the NFC tag.

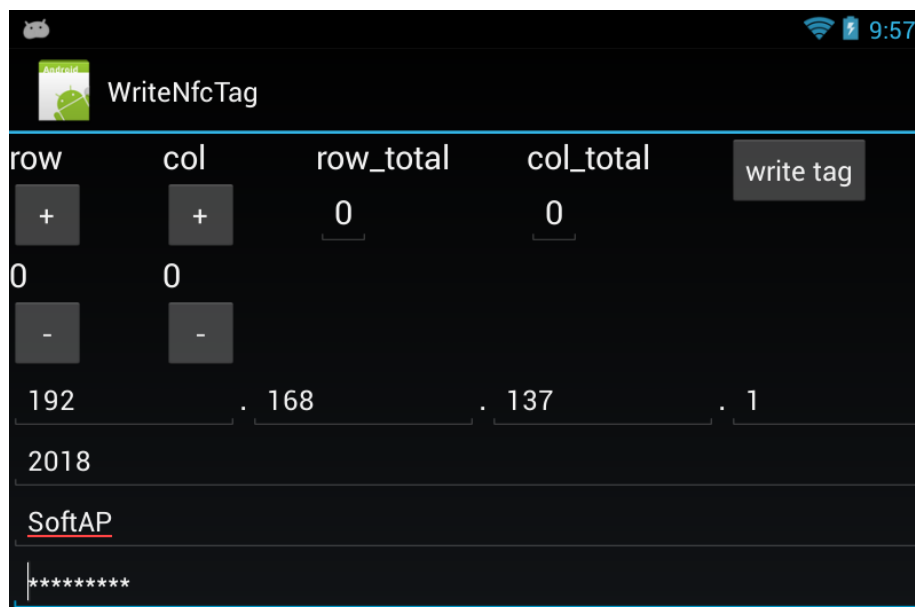


Figure B.1: User interface of the NFC tag writer app for reading and writing data on the NFC tags.

APPENDIX C

CROSS-SURFACE WEBSOCKET OODSS SERVICE

Object-Oriented Distributed Semantics Services (OODSS) [93] is an open-source framework to facilitate network communication and remote method invocation for cross-platform, information-centric distributed software applications. It uses features of S.IM.PL Serialization [38] such as data binding polymorphic objects and type system scopes. OODSS encapsulates service call and returns using command pattern in message objects. In OODSS, messages are subtypes of three base types: *request*, *response*, and *update*. Client application sends request messages to the server to invoke the service method on the server. Server then replies a response message to invoke the response method on the client. Server can also send update message to the client to invoke client side method without the request message.

In our system, the mobile application is developed in Android platform in Java. The application on the collaborative surface is developed as a Windows Store App in C# for Windows Runtime. Since It is not supported to run a network service in a Windows Store App, we designed our service architecture in a three party server/client system.

We implemented the cross-surface server in C# .NET platform. WebSocket is the underlying network protocol used in our implementation. WebSocket provides fully-duplex network communication channels over a single TCP connection between client and server. It keeps a persistent connection and enable frequent message exchange with small overhead. We implemented the mobile application and the application on collaborative surface as two clients that both connect to the cross-surface server. One client sends a request method to the server. Besides sending response to the

client, depending on the type of the request, the server may also send an update message to the other client to invoke its requested methods.

The type system scopes specify the contracts between the server and client applications by defining the types of messages that are supported. We listed all the messages used in our applications with their parameters and functions in Table C.1 - Table C.3. When the cross-surface OODSS server starts, it loads the type system scopes that contain all the required OODSS message classes in order to serialize and deserialize these messages.

Table C.1: Cross-surface OODSS message specification

Message	Sender	Receiver	Parameters	Function
TouchTagRequest	Mobile	Server	x-position y-position username	The mobile device notifies the server that a user touches an NFC tag, invoking TouchTagUpdate.
TouchTagUpdate	Server	Collab.	x-position y-position username	The server notifies the collaborative surface to initiate or relocate a portal.
Collab.ConnectRequest	Collab.	Server		The collaborative surface connects to the server to identify itself.
LogoutReuquest	Mobile	Server	sessionId	The mobile device logs out of the server.
LogoutResponse	Server	Mobile		Server notifies the mobile device that it is okay to log out
LogoutUpdate	Server	Collab.	sessionId	Server notifies the collaborative surface that a mobile device wants to log out.

Table C.2: Cross-surface OODSS message specification (Cont.)

Message	Sender	Receiver	Parameters	Function
ShareRequest	Mobile	Server	list of rich bookmarks	The mobile device shares a list of rich bookmarks to the collaborative surface.
ShareUpdate	Server	Collab.	list of rich bookmarks sessionId	The server sends the shared rich bookmarks to the collaborative surface.
ColorRequest	Collab.	Server	sessionId color in RGB	After connection of a mobile device, the collaborative surface sends the color assigned to the portal to the server.
ColorUpdate	Server	Mobile	color in RGB	The server sends the assigned color to the mobile device.
SearchRequest	Collab.	Server	search query sessionId	The collaborative surface requests the server to send a search query to a specific user.
SearchUpdate	Server	Mobile	search query	The server sends the search query to a specific user.

Table C.3: Cross-surface OODSS message specification (Cont.)

Message	Sender	Receiver	Parameters	Function
ShareToMobileRequest	Collab.	Server	list of rich book- marks sessionId	The collaborative surface requests the server to send a list of rich bookmarks to a specific user.
ShareToMobileUpdate	Server	Mobile	list of rich book- marks	The collaborative surface sends a list of rich bookmarks to a specific user.
LostConnectionUpdate	Server	Collab.	sessionId	The server notifies the collaborative surface that a mobile device has lost connection.

APPENDIX D

PARTICIPANTS BACKGROUND

We obtained the following background information of the participants from the pre-study questionnaire. The preferred places to conduct project planning at home were the on sofa / bed (19 participants), the computer desk (12 participants), and the dining / coffee table (10 participants). With the proliferation of mobile devices, it is not surprising that the participants picked sofa / bed over the computer desk.

As to the sources from which the participants gather information for project planning, 23 participants chose the Internet. 7 participants chose the Internet as the only source. Other common sources include magazines / newspapers / catalogs (12 participants), flyers or advertisements collected (9 participants), photos taken (6 participants). Participants also gathered ideas from model homes, home shows on TV, trips to brick-and-mortar stores, as well as museums, restaurants, and other building or indoor environments.

The participants used different tools in their daily project planning. Personal desktop or laptop computers were the most popular tools for project planning at home (21 participants). 13 participants used more than one computers when collaborating with others. Mobile devices like tablets and smartphones were also very popular (16 participants). One participant chose tablets and smartphones as the only tool. Some participants extended their small screen to the big screen TV. Although digital devices took the big roles in project planning, traditional non-digital tools such as pen and paper were not obsolete. In fact, 11 participants used pen and paper as their tools. One participant chose pen and paper as his only tool.

The participants used various ways to share information with their partners dur-

ing collaborative project planning. Sending Email was the most common method (15 participants). Showing content on a screen to the partner in person (14 participants) was also popular. Many participants used social network sites as a medium of sharing by posting to Facebook, Pinterest, etc. (11 participants). Other methods include showing content from paper sources in person (e.g. magazines/ newspapers/ catalogs) (8 participants), and showing content via web applications on the cloud (e.g. Google Docs) (8 participants).

At the end of the project planning, the participants used different methods to store the results. When the participants use the digital tools, the most common way was saving the results to a file on the computer (14 participants). Some participants would bookmark websites with the information for future reference (11 participants). Participants would also use web applications on the cloud (e.g. Google Doc) to store their plan (10 participants). As an alternative, when non-digital form of information was used, participants would digitize the plan by taking a picture (11 participants). Otherwise, they would keep the paper note physically (11 participants). Other less frequently used methods include sending the result as an email to everyone (6 participants), and using note keeping applications (e.g. Evernote, Google Keep) (4 participants). One participant indicated that he did not store the result.

Communication between the couples play important role in the home design and project planning. The design process usually started with one or both of the partners talking about their needs. Sometimes, the partners would talk about the projects long before they started gathering information for the projects and put concrete plan down on paper. Then, they would exchange their thoughts and ideas with their partners based on aesthetics and practicality when they look for materials and inspirations for the projects. The partners agreed upon mutual decisions through debate and discussion. Sometimes, the decision could take weeks to months to achieve.

APPENDIX E

PRE-STUDY QUESTIONNAIRE

1. Please provide a name or an id that you prefer. We only need this information to identify you throughout the study session. It doesn't have to be a real name.
2. What is your age?
3. What's your relationship with your partner?
4. Do you engage in home design with your partner? Yes/No
5. If yes, please give an example of how you and your partner generate your ideas, how the two of you make design decisions, etc.
6. If no, do you make plans for other projects (i.e. purchasing a gift, planning a trip, home renovation, etc.) with your partner or other family members together? please give an example on how you and your partner generate your ideas, how the two of you make design decisions, etc.
7. What role does technology play in these designs/projects?
8. Where do you usually conduct project planning (i.e. purchasing a gift, planning a trip, makeover a room, etc.)?
 - (a) on a sofa or bed
 - (b) at a computer desk
 - (c) around a coffee / dining table
 - (d) other:

9. What information sources do you use for such activity? Please choose all that you often use
- (a) web
 - (b) magazines/ newspapers/ catalogs
 - (c) photos you take
 - (d) flyers or advertisements you collect
 - (e) other:
10. What are your preferred tools/devices to use for such activity? Please choose all that you would use TOGETHER in your activity
- (a) with one PC/laptop
 - (b) with two or more laptop/PCs
 - (c) with tablets/smartphones
 - (d) with big screen TV that mirrors/extends the PC screen
 - (e) with pen and paper
 - (f) other:
11. If you include other people in the planning process for such projects how do you share the information you collect with them?
- (a) Sending Email
 - (b) Sharing content via web apps on the cloud (e.g. Google Doc)
 - (c) Posting to social media (e.g. Facebook, Pinterest, etc.)
 - (d) Showing them content on a screen in person

(e) Showing them content from paper sources in person (e.g. magazines/ newspapers/ catalogs)

(f) other:

12. How do you usually store the final plan?

(a) Save it to a file on the computer

(b) Use web apps on the cloud (e.g. Google Doc)

(c) Use note keeping apps (e.g. Evernote, Google Keep)

(d) Send an email to everyone

(e) Keep the paper note physically, stick it on something (fridge, computer screen, wall, door, etc.)

(f) Take a picture or scan the paper note

(g) Bookmark a website for its content

(h) other:

APPENDIX F

POST-STUDY QUESTIONNAIRE

1. What's your name or id you provide in the pre-study questionnaire?
2. How satisfying is browsing and collecting information from the web on the tablets?
Very unsatisfying 1 2 3 4 5 Very satisfying
3. What makes it satisfying/unsatisfying for you?
4. How satisfying is connecting tablets to the TV in the study?
Very unsatisfying 1 2 3 4 5 Very satisfying
5. What makes it satisfying/unsatisfying for you?
6. How satisfying is sharing the collected information from tablets to the TV using the swipe gesture
Very unsatisfying 1 2 3 4 5 Very satisfying
7. What makes it satisfying/unsatisfying for you?
8. How satisfying is making information composition on the TV?
Very unsatisfying 1 2 3 4 5 Very satisfying
9. What makes it satisfying/unsatisfying for you?
10. How would you rate the difficulty of viewing/exploring information shared by your partner?
Very difficult 1 2 3 4 5 Very easy

11. What makes it easy/difficult for you?
12. How would you rate the difficulty of viewing/exploring information shared by your partner?
- Very difficult 1 2 3 4 5 Very easy
13. What makes it easy/difficult for you?
14. Do you find the metadata useful?
- Not useful 1 2 3 4 5 Very useful
15. Where do you find it to be useful? Or why is it not useful?
16. How well does the system support discussion between you and your partner?
- Very poor 1 2 3 4 5 Very well
17. How well does the system support you to be aware of what your partner is doing?
- Very poor 1 2 3 4 5 Very well
18. Please compare the system with your usual tools to use in project planning with your partner in terms of supporting discussion and awareness.
- What does the system do better? What is missing?
19. How much do you think that you contributed to the task?
- 100% means you contributed to most or all of the work while your partner contributed very little or nearly none
- 0% 1 2 3 4 5 100%
20. Do you feel that you are more involved in the process (making more contribution) than you usually were in similar activities

I contributed less and my ideas are more neglected than usual 1 2 3
4 5 I contributed more and my ideas are more treasured than usual.

21. How well do you feel the composition you and your partner created represents both of your interior design preferences?

Very poor 1 2 3 4 5 Very well

22. Please explain what aspects of the system helped you make more contribution / express your ideas to your partner or prevented you from doing so.

23. Can you provide an example of how you collaborated with your partner to make your composition?

(i.e. was there anything you feel is notable about how you make decisions on theme and layout, how you choose items)

24. How is your collaborative process different from your previous experience with your partner?

(i.e. was there anything you feel is notable about how decisions were made, images discussed, or layout format?)

25. Please provide any additional comments about what it was like to collaboratively create a home makeover composition with your partner.

26. Would you choose to use this system in similar activities with your partner over your usual methods?

Very unlikely 1 2 3 4 5 Very likely

27. Compared to your usual methods, what was your favorite part of using this system?

What was enjoyable about the experience? Is it more effective or less? Is there any feature that you wish you had before?

28. Did you find some item you collected that you would like to buy after the study?

Yes / No

29. Do you want to keep the information composition for your future reference?

Yes / No

30. If you want to look at your information composition after the study, we can send the information composition to you.

Please provide us your email address and preferred username below.

31. What other activities do you think this system could be used for?

32. What changes would you make to this system?

Are there any functions you would like to add to it? Any suggestions? Anything you don't like?