YourSphere: Supporting Flexible Environmental Switching in Open-plan Workspaces via Augmented Reality

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Abstract

Background The need for collaborative shared workspaces fostered the design of various types of space configurations (e.g., open-plan and activity-based workspaces). More recently, researchers have shown that mid-air augmented reality (AR) and virtual reality (VR) displays can also be used as a complement or alternative to traditional physical spaces, by reducing the distractions of shared environments. However, AR pervasive displays have the opportunity to impact workspace design even further and in ways that were not considered in prior works. In this paper we aim to explore the design opportunities that peripheral mid-air AR displays offer to support easy environmental switching in a shared open-plan workspace.

Methods We used a modified version of a speed-dating method with text-based scenarios and interviews. We generated five scenarios that are derived from the context of a shared workspace: high-level concentration, low-level concentration, 1-to-1 communication, group communication, inspiration and relaxation. We therefore recruited 18 volunteers who identify themselves as interaction designers who work in an office. All inverviews were conducted individually, in person or via a video chat if the participant was located abroad.

Results Participants defined mid-air AR displays to be used as flexible barriers, indirect communication channels, background ambient displays, and mediators to the external environment. Participants demanded an integrated spatial change except for certain properties such as height and transparency. These choices are related to the participants' intention to reduce the unnecessary complexity.

Conclusions In this paper, we explored possible usages of mid-air AR displays for environmental switching in a shared open-plan workspace with the concept of a virtual partition from the users' viewpoint. Our study not only discussed overcoming disturbance in a workspace, but also approached supporting activity changes including interaction with coworkers that often happen in a shared workspace. We believe that this study can help space and interaction designers to understand how they can apply peripheral mid-air AR displays in a shared workspace. This will lead users to have customized workspaces that better fit their own workstyles.

Keywords Peripheral mid-air Displays, Augmented Reality (AR), Environmental Switching

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1. Introduction

Open-plan workspaces are common space layouts used in offices because they well support collaboration between workers (Allen, 1973, Palvalin, 2017) and efficient in use of space (Burkus, 2016). To overcome the problems related to surrounding disturbances and privacy that typically affect open-plan workspaces (Kim, 2013), activity-based workspaces (ABW) were proposed as an alternative. The main idea of ABWs is to let people freely move around spaces designed for specific types of activities, allowing workers to find the place that is best adapted to the task undertaken. However, researchers demonstrated that people tend to remain in one place while they are working (Hoendervanger 2016). This suggests that ABWs may be ineffective.

Augmented/Virtual reality recently emerged as a possible technological solution that could bridge the two design approaches, open and closed. Instead of closing an open space with physical partitions or cubicles, augmented reality offers the opportunity to create virtual partitions (Lee, 2019) and virtual environments (Ruvimova, 2020) that can shield users from surrounding disturbances while maintaining a space open for everyone else. Differently from in ABWs, workers do not need to move from their seat to find a suitable working space; rather, they can customize their current space by the superimposition of graphical elements displayed through AR/VR technology. Researchers demonstrated that this approach decreases the effects of surrounding disturbances and improves both the productivity and satisfaction of workers in open offices (Lee, 2019, Ruvimova, 2020). However, while these works are the first to show the potential of virtual displays to augment the physical surrounding spaces, they mainly focus on the specific issue of mitigating surrounding distractions. We therefore see an opportunity to further explore the design space for applications that integrate augmented reality technology with physical workspaces.

In this paper, we explore the extended usage of AR peripheral mid-air displays by focusing on how it can support changes in activity occurring in a shared open-plan workspace from the point of view of the users. We believe that with the help of recent growing AR technology, we can suggest alternative ways to overcome the limitations of the current workspace design. As a way of exploring a new interactive system, we conducted a scenario-based user study with interaction designers who are also office workers. We used the concept of a virtual partition (Lee, 2019) to develop our scenarios. Our collection of feedback from participants on the possible uses of peripheral mid-air displays according to their needs and social norms in a specific context allowed us to introduce four novel uses for them.

2. Related work

2. 1. Using peripheral displays for ambient effects

In relation to HCI research, environmental factors in the workspace have been used for delivering ambient information (Ishii, 1998, Macintyre, 2001, Meagher, 2007) or for providing an enhanced workspace by blocking sound selectively (Takeuchi, 2010), changing the atmosphere (Zhao, 2017), and reducing distractions (Lee, 2019, Ruvimova, 2020).

For providing an enhanced environment to workers, Takeuchi (Takeuchi, 2010) suggested the concept of a *weightless wall* that selectively blocks sound using noise-canceling headphones. Zhao et al. (Zhao, 2017) introduced mediated atmospheres (MA) that can change the ambience of a workspace. They used lighting as a central factor and applied beam-projected visual images with sound. They found that five different conditions (neutral, kites, city, forest, library) had different effects on the users' perception and physiological state. To avoid distractions in open-plan workspaces, Lee et al. (Lee, 2019) showed a possible usage of AR mid-air displays and Ruvimova et al. (Ruvimova, 2020) suggested VR closed offices.

2. 2. Context switching with shape–changing surfaces and AR/VR displays

In a shared workspace, several HCI researchers tried to integrate digital information with shape-changing surfaces (Gronbaek, 2017, Kwoka, 2008, Takashima, 2016) to support real-time changing of interactions among individuals and groups. However, even though they considered activity switching in real space, the changes were constrained by the limitations of the specific shapes of their physical prototypes.

Free from physical constraints, Ens et al. (Ens, 2014) improved task-switching time by using head movement and empty space around the user to put up virtual windows. Surale et al. (Surale, 2019) focused on mode switching in a VR environment using bare-hand mid-air interaction techniques. They demonstrated bare-hand, mode-switching techniques with exemplary line-drawing tasks. In the context of adaptive MR, a study by Lindlbauer et al. (Lindlbauer, 2019) approached daily context switches (task/environment) by automatic control of when and where applications are shown, using users' current cognitive load and knowledge about their task and environment.

3. Overview of the study

The concept of a virtual partition in this paper is derived from related studies that used peripheral displays for ambient effects and from the recent development of AR/VR devices. The concept presupposes that virtual digital elements, which are nonphysical, can change the environmental characteristics of one's workspace.

We used a modified version of a speed-dating method by Davidoff et al. (Davidoff, 2007) with text-based scenarios and interviews. Between the transition from sketching to prototyping in a design process, the speed-dating method allows design teams to explore possible futures with target users. Eventually, this method helps reduce the risk of developing undesirable products that people will not accept by revealing hidden needs, social boundaries, or better directions or by reframing the problem (Zimmerman & Forlizzi, 2017). In our study, after having a concept of a virtual partition and before generating real prototypes, we applied this speed-dating method to reveal any better directions that we might have missed. Speed dating has two main forms—storyboards and user enactment (Zimmerman & Forlizzi, 2017). Both approaches expose target users to new design concepts in a familiar situation. We chose a style of storyboards with text-based scenarios and instead of comparing scenarios, we focused on discovering participants' needs and desires. In designing a new interactive system, Rosson and Carroll (Rosson, 2009) demonstrated the advantage of using a scenario-based design, which enables rapid communication about usage possibilities and concerns among many different stakeholders, especially within an interactive system design. Scenarios are also advantageous because they are able to minimize simplifying problems or reusing familiar solutions and to focus on the usage context.

Since the intention of applying a peripheral mid-air AR display is to support environmental switching, we could predict several usage contexts. In the next session, we will introduce how we generated the scenarios used in this study.

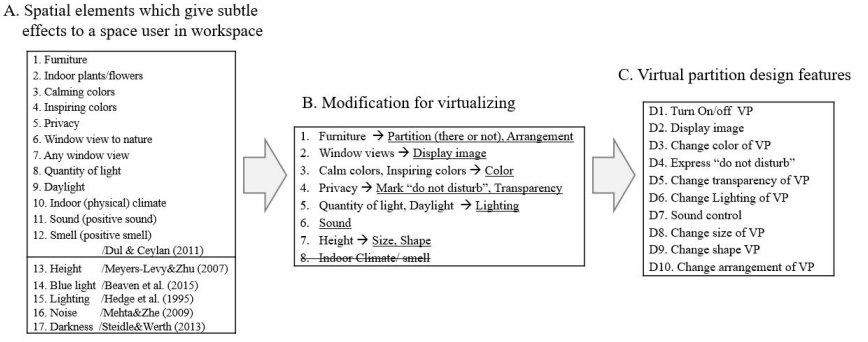

Figure 1 Modification of design features from physical workspace as applied to a virtual partition

4. Materials

We defined the boundary of our study by using the metaphor of a partition from a previous study (Lee, 2019). In order to obtain the design elements for a virtual partition, we borrowed a set of physical design frameworks from research about creative space design by Dul and Ceylan (Dul & Ceylan, 2011). Then we added other elements, such as height, noise, and color, from related space-design research (Figure 1-A).

To allow those design elements to become virtual, we modified them as shown in Figure 1-B, and reorganized the schematic as shown in Figure 1-C. The "furniture" element was limited to a partition. We interpreted the design elements, which require views or images such as an outdoor view and indoor plants, as a visual display by considering the limitation of virtual elements. For a "privacy" element, we interpreted it as a "do-not-disturb" mark and a means of controlling transparency to obtain privacy from others. With regard to "height," we expanded it to a changeable size and shape to maximize the advantage of a virtual space. Among nonvisual elements, we decided to add "sound" because it is the most influential factor in the workspace in comparison to other features (Kim, 2013).

Five main activities are derived from the context of a shared workspace: high-level concentration, low-level concentration, 1-to-1 communication, group communication, and inspiration and relaxation. We tried to ensure that each of our ten design elements would apply to a scenario that suits it. To refine and elaborate upon these scenarios, we conducted pilot studies with two participants. We removed repetitive parts, reduced complexity and improved stories to help participants easily imagine the situations. As a result, every scenario contains one main and one sub-activity that shows a chance of switching two given design features. The summary of each scenario is as follows.

1. High-level Concentration: Shared open workspace → space changed for high concentration ("do not disturb" mode) (D1,D4)
2. Low-level Concentration: Shared open workspace → space changed to one's own working space. (D3,D7)
3. 1-to-1 Communication: Personal work environment → space changed for 1-to-1 communication (D8,D10)
4. Group Communication: Small-scale communicative environment → space changed for group communication (D5,D9)
5. Inspiration and relaxation: Inspirational space → space changed for relaxation. (D2,D6)

Figure 2 Abstract image of virtual partitions

Figure 2 is suggested as supporting material to show how mid-air displays can be located surrounding a user as environmental features and how they can have flexible shapes and scales.

5. Participants and procedure

We recruited 18 volunteers (7 females) between the ages of 25 and 36 (mean 28.5, SD: 3.3) with a degree in industrial design or industrial engineering. All participants have a minimum of 2.5 years of professional experience as interaction designers. Five work in large corporations (more than 100 employees), and the rest are registered in the graduate program of industrial design at the authors' institution (one master's degree student and twelve PhD students, five of whom had prior industry experience).

All participants work with 20 to 80 other colleagues in the same shared space each day, which is organized in one of the following layouts: seven participants have their desks in a completely open shared space, six are delimited by 2-sided partitions, and the rest are delimited by 3-sided partitions.

All experiments were conducted individually. Most participants visited our site; however, as two participants work abroad, we used video chat to conduct interviews with them. Three company workers also live in another city, so we took a chance when they visited our institution. When the participants arrived, the main researcher briefly introduced the experiment and collected their demographics. The text-based scenarios were given in random order without descriptive drawings in order to reduce the participants' bias. Figure 2 was provided to encourage the participants' imagination with regard to virtual partitions. The participants were asked to respond in the form of written texts or drawn images about interaction methods according to each scenario. Before moving on to the next scenario, participants were asked to explain their ideas in words, which we recorded. Each scenario took 10 to 15 minutes, and we allowed for a total of approximately 90 minutes, including for follow-up questions. For the record, we used both a voice and a video recorder. The participants were compensated for their time with 30 USD in local currency.

6. Result and Findings

The main researcher conducted an open coding analysis based on the voice recording transcriptions, and the other researcher reviewed the codes to check whether she could agree with coding. The two researchers discussed the codes they disagreed on to find an agreement. Then, the researchers created an affinity diagram to determine the main themes and analyzed the data repeatedly with video recordings and drawings. As a result, we could see the possible usages of a virtual partition and how it can increase flexibility in work environments.

Participants thought that a virtual partition was more flexible than a physical partition, and Figure 3 shows how they described a virtual partition as simply virtualized current physical partitions (p3), flexible displays extruded from drawn lines (p18), extended screens from current physical displays (p6, p10), and a virtual cylinder (p5) or spheres (p12, p14) that surround a user.

The result indicates more concrete usage concepts of AR peripheral mid-air displays when one applies AR peripheral mid-air displays in the context of environmental switching for work-related activities.

Identified benefits of using a virtual partition are categorized into four characteristics, which are using it as a flexible barrier, an indirect communication channel, a background ambient display, or a mediator to the external environment.

Figure 3 Drawings from participants: virtual partitions described as simply virtualized current physical partitions (p3), flexible displays extruded from drawn lines (p18), extended screens from current physical displays (p6, p10), a virtual cylinder (p5)/spheres (p12, p14) that surround a user

6. 1. Virtual partition as a flexible barrier

6. 1. 1. To control the level of openness of users' workspace:

First of all, participants (P2,3,6,8,12) wanted to **personalize their space** (Figure 4-A) by putting all of their contents on virtual displays. P2 wanted a personal virtual partition for privacy saying, "When someone suddenly comes in and starts talking, it is sometimes embarrassing because of what's on your computer" (P2). Security issues were also pointed out. "I wish it (the workspace) could not be seen by others except me, because it's an open space, and people from other departments may not be allowed to access the document I'm working on" (P6). A virtual partition is also applied to a different perspective; participants explained the ability to **share space** (Figure 4-B) with a certain group of people from the perspective of a coworking environment. "I hope I can share it selectively" (P12).

6. 1. 2. To control the level of openness to users' surroundings:

Participants applied a virtual partition to **block the visual area** to reduce users' perceptual load (Figure 4-C). The application was mostly related to each person's desire for concentration (scenario 2).
"I kept thinking about the degree of visual pollution that is caused by perceiving someone else's personal space ... It is not a space for one person. There is a problem of sharing and cognition" (P12). To reduce the perceptual load, the participants controlled transparency (P1, 6), blocked their view except within the working area (P15, 16), minimized others' information (P12), or only wanted to see and hear registered people (P5, 6). However, that does not mean that people just wanted to be disconnected. As they were in the context of a shared working environment, several participants(P3, 9, 12, 17, 18) wanted to see and hear their surroundings to interact with their colleagues, even while blocking their view.

Mid-air AR displays can let users choose which part of space to share with others and decide the level of openness to the surrounding environment.

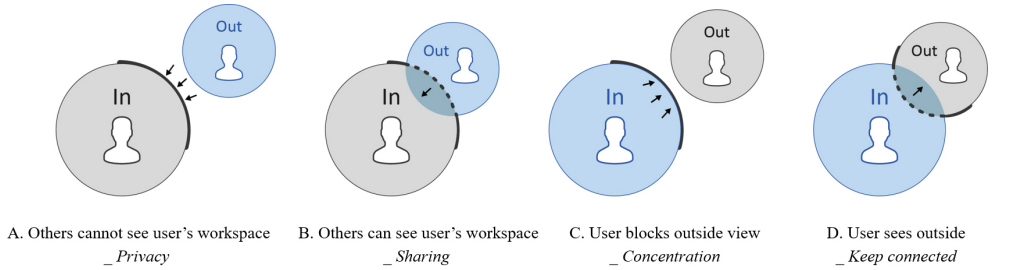

Figure 4 What to see and what to share

6. 2. Virtual partition as an indirect communication channel

Participants wanted indirect expression through a virtual partition. They found it difficult to communicate a "do-not disturb" (DND) status directly to others. "Of course, this may also be an individual difference, but in fact, in an environment that has some teamwork, expressing, 'I want to focus on something, I don't want to be disturbed' could be perceived as being too aggressive and contrary to teamwork" (P2). Another

company employee, P17, needs to engage in more humane and social communication.
There were multiple indirect ways of expressing his/her state to others: by the partition itself (P2, 7, 9, 14, 15, 18), by its color/ material (P3, 8, 16, 18), by the color of small light (P4, 5, 6, 10), and by a simple mark (P1, 3, 12). When treating the partition itself as a message, P9 thought that keeping the partition up seemed impolite and unwelcoming, so she wished to turn it off when there was a visitor. She thought that doing so would be possible when in cases of a virtual partition. P2 suggested an autonomous mode change of a partition according to each user's degree of concentration.

Mid-air AR displays can be an indirect channel to express users' states.

6. 3. Virtual partition as a background ambient display

Not changing spatial elements individually, participants (P3, 6, 7, 11, 12, 14, 17) often wished to change the environment as a whole, so that they could feel as if they were somewhere else, such as a specific café or city or nature. "Is it okay not to use color? I think it's better to be in a different room than to change the color" (P11). Figure 5 shows the different ways of expression; P6 suggested a window that shows the outdoor view of another city, P11 changed the whole image of the virtual partition itself to show another place, and P14 changed the outside view of a virtual partition while maintaining the partition as a part of the workspace. "As you see, I even added the effect of raindrops on windows. To have the real feeling of being in Paris, I thought I should see different images according to the viewpoint. So, I got 360-degree images as if I was really sitting in a room in Paris. (P6)."

Mid-air AR displays can provide a complete environmental change without the need to change spatial elements individually.

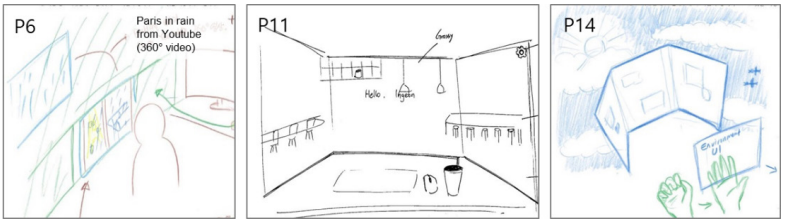

Figure 5 Replica of favorite places

6. 4. Virtual partition as a mediator to an external environment

Few participants understood the location of a virtual partition—room in room—and showed the possible connection with the external environment. This feature is especially related to brightness; the real lighting becomes dim when the partition is darkened. "When it is interlocked, the actual lighting becomes dark as well, and when it is not needed, it can be separated (P10)." P12 only changed the opacity of a virtual partition by considering the outside brightness, and P8 controlled the volume of music according to the outside noise level. "I thought of a smart environment and imagined that the noise level was presented here. That (noise line) moves in accordance with the outside noise, ... and I can control this (this decibel vertical line). If I want to hear something at a level lower than this decibel, then I move the line down like this. Then, the system will play the music automatically for it, according to the personal circumstances" (P8).

Controlling mid-air displays can be done jointly with external environmental changes.

7. Discussion

The focus of this study was on usage of peripheral mid-air AR displays that supports environmental switching in a shared workspace. In the context of switching, participants suggested beneficial uses of peripheral mid-air AR displays, and Figure 6 visualizes those ideas.

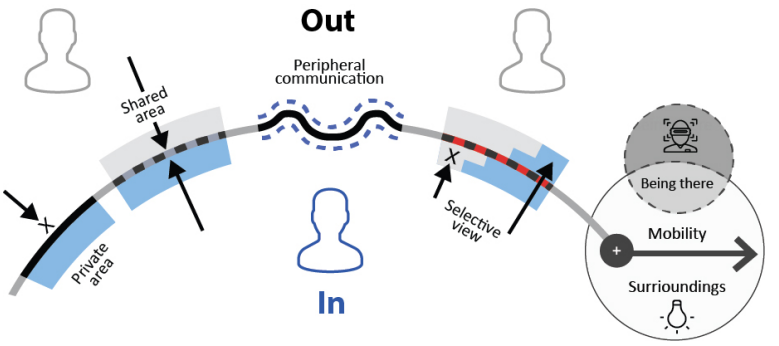

Figure 6 Usages of a virtual partition

Unlike previous studies (Zhao, 2017, Lee, 2019, Ruvimova, 2020) that were focused on augmenting the workspace for a single user, our study is focused on supporting changes to activities that include interactions between coworkers.

Firstly, participants applied mid-air AR displays to achieve a desirable visibility of their workspace to others and protection from outside disturbance. Previous studies (Lee, 2019, Ruvimova, 2020) only highlighted the value of blocking outside disturbance; however, the result of this study shows that people still want to be connected to the outside and that there is a need to control that desire. When Grubert et al. previously discussed the future of office design, they noted that VR users may experience a loss of situational awareness and physical isolation (Grubert 2018). We believe that our research fully addresses that issue.

Secondly, with mid-air AR displays, participants suggested indirect ways for communicating personal status between workers. Previous works that used ceilings (Meagher, 2007) and kinetic lighting displays (Glynn,2014) delivered collective information of a building and workers, but personal peripheral displays can be more personalized in scale and can have diverse design features. This should let coworkers understand each other better and know, for example, when they can interrupt others or not (George, 2019).

One interesting finding is participants' tendency to change the environment as a whole. Even though we asked participants to change individual spatial elements separately as activity changes, participants changed the environment as a whole except for in certain cases, such as controlling height and transparency. This behavior is related to the participants' intention to reduce unnecessary complexity. In the study of Zhao et al. (Zhao, 2017), they changed atmosphere by changing diverse spatial elements altogether following the advice of professionals. We believe that mid-air displays would give users comparable effects. Letting users choose among designed spaces provided and modify limited functions would be a proper strategy to take for the next step.

A limitation of our study is that participants' background could have influenced the result. Our participants had the same nationality and similar work styles, and the results could have been different if the study was conducted with people from different cultural backgrounds. We limited the usage context to a workspace shared between coworkers, but if the work environment is changed to a home or cafe, there will be different types of people around, which will influence the behavior of users.

8. Conclusion

In this paper, we explored possible uses of mid-air AR displays for environmental switching in a shared open-plan workspace with the concept of a virtual partition. Our study not only discussed overcoming disturbances in a workspace (Lee, 2019, Ruvimova, 2020,) but also approached supporting changes to activities involving interactions with coworkers that often happen in a shared workspace.

Mid-air AR displays can have four usages: flexible barriers, indirect communication channels, background ambient displays, and mediators to the external environment. One interesting finding is that participants demanded an integrated spatial change except for on certain properties, such as height and transparency.

We believe that this study can help space and interaction designers understanding how they can apply peripheral mid-air AR displays in a shared workspace. This will lead users to have customized workspaces that are more fit for their own working styles.

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Appendix

Five scenarios that are used in the paper.

1) *High-level Concentration*. Tim wants to focus on his work without being disturbed. Therefore, he activates the "no-disturbances" mode in his virtual partition. Later, Jenny approaches him to talk about an email but realizes that Tim is in "no-disturbances" mode (D1, D4).

2) *Low-level Concentration*. Today, the office is very noisy, and Mori is in a bad mood. She turns on the auditory feedback feature to shield herself from the office noise, and adjusts the color of the partitions to soothe her mind. Eventually, Mori feels better and is very productive, so she changes the partition color again to focus on her work and accomplish a lot (D3, D7).

3) *1 – 1 Communication*. Jon is working alone on a design while using the virtual partition to remain focused and to gain visual and auditory insulation. Then, he asks Sarah to join him to receive feedback. When she reaches his table, Jon quickly changes the arrangement of the virtual partition and the size of his space, to include her in his field of view (D8, D10).

4) *Group Communication*. Mark is holding an important meeting with a lawyer from another firm and sets his space with the virtual partition in half-transparency mode for privacy during the discussion. After the meeting, he shows his client around the office, and the colleagues who want to provide a demonstration of their product, move or change the shape of their partitions to create an open space (D5, D9).

5) *Inspiration and relaxation*. Jane is preparing a presentation and using several images and text around her virtual partition for inspiration. After several hours of work in front of the screen, her eyes hurt and she decides to change the intensity of the lights from the partition to comfort her eyes and make the environment more relaxing (D2, D6).