Investigating Document Layout and Placement Strategies for Collaborative Sensemaking in Augmented Reality

Weizhou Luo
weizhou.luo@tu-dresden.de
Interactive Media Lab Dresden
Technische Universität Dresden
Dresden, Germany

Anke Lehmann
anke.lehmann@tu-dresden.de
Interactive Media Lab Dresden
Technische Universität Dresden
Dresden, Germany

Yushan Yang
yushan.yang@mailbox.tu-dresden.de
Interactive Media Lab Dresden
Technische Universität Dresden
Dresden, Germany

Raimund Dachselt[*][†]
dachselt@acm.org
Interactive Media Lab Dresden
Technische Universität Dresden
Dresden, Germany

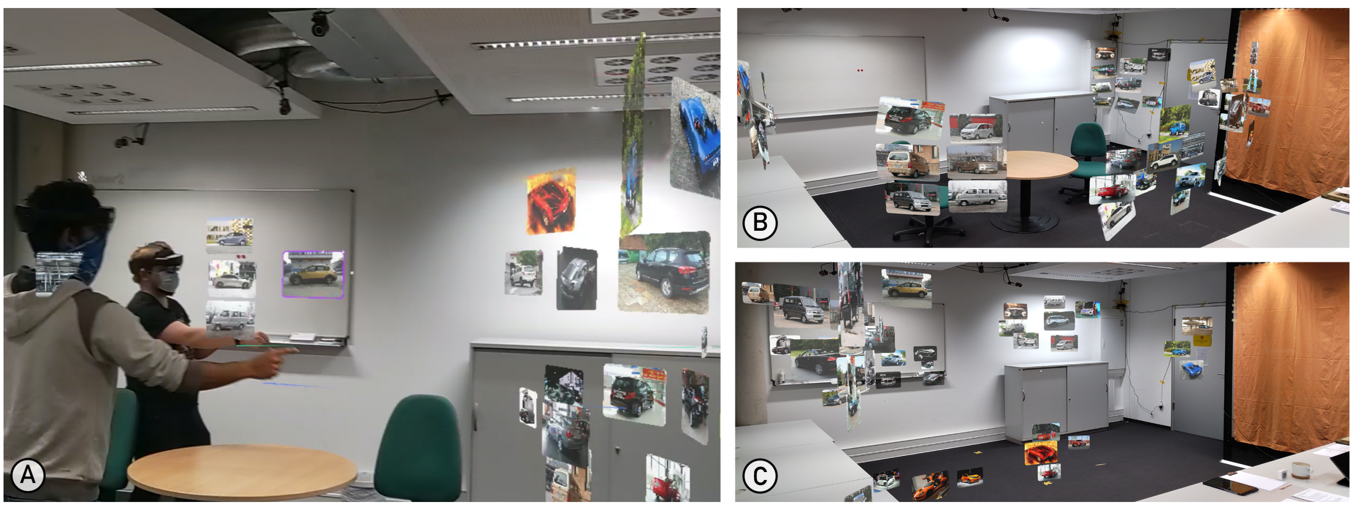

Figure 1: In this study, we compare the virtual content placement and layout in AR in two types of room settings. (A) depicts two participants placing images collaboratively for a categorization task using ray-casting interaction. (B) and (C) show the two study conditions *fully-furnished room* and *less-furnished room* with the final content arrangement made by participants.

ABSTRACT

Augmented Reality (AR) has the potential to revolutionize our workspaces, since it considerably extends the limits of current displays while keeping users aware of their collaborators and surroundings. Collective activities like brainstorming and sensemaking often use space for arranging documents and information and thus will likely benefit from AR-enhanced offices. Until now, there has been very little research on how the physical surroundings might affect virtual content placement for collaborative sensemaking. We therefore conducted an initial study with eight participants in which we compared two different room settings for collaborative image categorization regarding content placement, spatiality, and layout. We found that participants tend to utilize the room's vertical surfaces as well as the room's furniture, particularly through edges and gaps, for placement and organization. We also identified three different spatial layout patterns (panoramic-strip, semi-cylindrical layout, furniture-based distribution) and observed the usage of temporary storage spaces specifically for collaboration.

[*]Also with, Cluster of Excellence Physics of Life, Technische Universität Dresden.
[†]Also with, Centre for Tactile Internet with Human-in-the-Loop (CeTI), Technische Universität Dresden.

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CCS CONCEPTS

• **Human-centered computing** → **User studies**; **Mixed / augmented reality**; *Collaborative interaction*; **Computer supported cooperative work**.

KEYWORDS

user study, spatiality, sensemaking, content organization, grouping, physical environment

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1 INTRODUCTION & BACKGROUND

The advent of affordable Virtual and Augmented Reality (VR and AR) head-mounted displays (HMD) brings new opportunities for workspaces. One main advantage of immersive HMDs is that they have nearly infinite display space compared to 2D monitors. However, complete isolation from the real world is not always desirable, especially in work settings. In contrast to VR, AR maintains the connection to other people and the physical environment, which allows retaining social awareness and simplifies the integration into existing workflows. Hence, it has a strong potential for collaboration in professional scenarios. Sensemaking and brainstorming are essential activities in many professional areas, which usually involve several stakeholders, such as journalism and design. Moreover, human beings naturally rely on the space to structure their ideas throughout the cognitive process. Thus, we believe that future workspaces will extensively adopt AR techniques. In particular, tasks like collaborative brainstorming and sensemaking can benefit from AR directly by the extended display space, ease of collaboration, and low barrier to adapt to the current workflow.

While prior studies showed that sensemaking and brainstorming activities benefit from spatial content arrangement, most research focused primarily on conventional desks or pinboards [8, 11, 18], large vertical displays [1, 2, 10], interactive tabletops [9, 17], or mobile devices [19, 22]. Regarding the content placements and organization, different spatial configurations could be observed such as incremental layout [18] and row-column-clusters [10], resulting from individual use (e.g., [1, 10, 18]) or co-located collaboration (e.g., [2, 9]), as well as the type of surfaces used. Furthermore, territoriality plays an important role by using workspaces such as shared or group spaces, (temporary) storage spaces, and individual spaces during collaboration (e.g., [2, 17]). Recently, Lisle et al. [12] proposed a VR prototype called Immersive Space to Think, which demonstrated how users can benefit from the extensive immersive space for a text sensemaking task by organizing content as a dome-like structure in VR. Similarly, Yang et al. [20] found that using a VR memory palace to build connections between information and a virtual cafe shop (the loci) can greatly increase the memorability compared to the baseline condition. He et al. [7] demonstrated a VR whiteboard tool for creative collaboration and highlighted users' preference for a mirrored layout, similar to face-to-face. These studies support the value of immersive HMD for some high-level cognitive tasks.

Apart from work like the one by Ens et al. [4], who proposed spatial analytic interfaces in AR considering user's context and supporting analytic tasks in situ, previous research for immersive window layout and view management mainly concentrated on single user scenarios and VR platforms. For example, Satriadi et al. [16] designed three hierarchical multi-view layouts in VR for geospatial information exploration based on an elicitation study and found that users tend to prefer a spherical cap layout. Liu et al. [13] integrated multiple small data visualization blocks in VR and found that users prefer a flat layout for small collections and a semi-circular layout for large collections. Additionally, some prior work took advantage of the physical surrounding for providing contextual visualization and interaction to enhance the immersive experience. For instance, to embed the virtual content to the real world, Ens et al. [5] proposed spatial constancy and visual saliency as heuristic constraints and Nuernberger et al. [15] demonstrated an automatic alignment technique to help snap virtual objects according to the physical surroundings. Recently, Chae et al. [3] introduced an AR photo management prototype that utilizes the physical affordance of daily objects for photo organization. Conversely, the physical surrounding also influences user experience. Shin et al. [6] found that the large indoor spaces aid a sense of presence and narrative engagement whereas the high density of space increases users' perceived workload.

Despite this previous research, we still lack an understanding of how the physical environment of, e.g., an office affects virtual content layout and placement in AR during a collaborative activity. In particular, we are interested in research questions like: How do users place content in an immersive 3D environment for sensemaking and brainstorming? How do they make use of the real space and furniture for their virtual content arrangement? How do multiple users arrange content collaboratively?

As a first step, we focused on one aspect of sensemaking – sorting and grouping. We conducted a preliminary user study with eight participants, comparing two differently furnished room settings for a collaborative image categorization task, and investigating the users' workflow, content organization, and spatial arrangement. We contribute first insights concerning the collaborative usage of space in AR and the relation of virtual documents to the real environment. In this ongoing work, we present our results and a discussion about observed patterns from three facets: (i) the spatial layout patterns of clusters (i.e., panoramic-strip, semi-cylindrical, furniture-based distribution), (ii) the spatial placement of content (i.e., using vertical planes, free gaps, or furniture-oriented edge-sensitive placement), and (iii) territoriality (e.g., temporary storage spaces).

2 USER STUDY

To get first insights into the real-world room environments' effect on collaborative content layout and placement, we narrowed down our research questions. We are especially interested in: How is content placed in AR for sensemaking activities? How do room features and its furniture affect users' content placement in AR? How do multiple users coordinate the space and place AR content together? Therefore, we designed a within-subjects experiment with two study conditions: fully-furnished room and less-furnished room. We chose a card sorting task (image organization and grouping) as a low-level sensemaking task (similar to [18]).

Setting and Apparatus: We selected a spacious lab room and defined the study area which includes one semi-opened boundary (separating participants and experimenters) and three closed surfaces (e.g., walls) with the two corners. The room was chosen so that the experiments can be performed well with a sufficient social distance due to the COVID-19 pandemic. Additionally, the furniture items in the room for both conditions were selected and arranged to recreate a typical meeting room environment. The *fully-furnished* condition (Figure 1(B)) contains various furnishings and room components: a grey curtain with a long side table (left side of the room), a short side table (close to experimenters on the front side), an orange wall and the door (right side), a cabinet and a whiteboard (back side), a round table with two office chairs (room center), and a small garbage bin (under the whiteboard). In contrast, the *less-furnished* room (Figure 1(C)) has everything without the garbage bin, the round table, and the office chairs.

We used Spatial[1] as the software platform for collaboratively working in AR. It is a space-adaptive, cross-device, collaborative working platform for immersive HMDs like Microsoft HoloLens. Spatial supports two modes of interaction: the ray-casting (a ray starting from the palm of the user's hand) for objects out of reach and the direct manipulation by hand, that can be used when objects are near users. Users can pinch their thumb and index finger to select and hold an object, either by a direct grab of near or by air tap for remote objects, and then move or rotate it. With two hands selecting (either ray-casting or direct manipulation), users can scale up objects by moving the hands further apart or vice versa. Notably, a combination of interactions is also allowed, for instance, moving and rotating at the same time, which is consistent with the real world experience. We chose this platform for our preliminary experiment due to its vision of leveraging AR for sensemaking and brainstorming tasks, and it enables multiple users to interact with images in an intuitive way. Hence, it is capable of performing our targeted task at a commercially available level and allows users to focus on content placement in AR instead of software usability. We used the application on four Microsoft HoloLens 2, two for participants to perform the tasks and two for observing by the experimenters.

Participants: We invited eight unpaid participants (three female and five male, 23-39 years old) from our university (seven from the computer science department, one from the psychology department). Six participants frequently use traditional brainstorming techniques (pen and paper, mind mapping with whiteboard or chalkboard, and sticky notes), and three participants sometimes use digital brainstorming techniques (whiteboard app, mind mapping tool, sticky notes app, and others). Six participants responded that they frequently use immersive headsets (AR: 5, VR: 1). The rest either seldom uses immersive headsets or had no prior experience with such devices. Moreover, all of them felt generally positive to work with others as a team to solve tasks. The eight participants formed pairs of teams (T1-T4), where the team members knew each other, except for T3.

Procedure: Upon arrival in the lab, participants were first given an introduction to the study[2], signed a consent form, and filled out a demographic questionnaire. Then an experimenter guided each team to wear the HoloLens 2 and complete calibration for their eyes. Before the study sessions, the teams had a training session including an introduction given by an experimenter about the visualization and interaction of Spatial. Afterwards, participants were allowed to practice required operations freely with 10 exemplary images until they felt confident. During the study, teams were asked to perform a card sorting task on 50 images within 20 minutes (fruits or cars [3]) under different room settings (fully-furnished or less-furnished). These images were evenly distributed throughout the room as 10 stacks initially (each stack with 5 images). Teams were asked to freely group and cluster these images; they were informed that there were no specifications for sorting criteria, strategy, or fixed solution. However, the teams should come up with as many categories as possible and both agree with the final outcome. Furthermore, we encouraged them to find minor categories with only a few images. After completing the task, teams were asked to briefly explain their categories. Then a short break was given before starting the second study condition. Both room conditions and datasets were counterbalanced and each team finished both sessions. In the post-study interview (30-min semi-structured), the teams were asked about their methods and impressions. The experiment lasted around 120 minutes per team.

Measurements and Data Analysis: As our research focused on observing the users' layouts and placement, each session was video and audio recorded. We used two traditional cameras to record the user behavior in the physical environment and a HoloLens 2 worn by an experimenter to capture the content placement in the AR space of Spatial. Also, two tablets (Apple iPad Pro 12.9", 2020) were used to record the virtual environment through the Spatial mobile application. Two experimenters in the study room observed the participants' behaviors and took notes in a semi-structured protocol. For the subsequent data analysis, we sorted and categorized the protocol notes of the experiments along with the video recordings into three main categories namely (i) collaboration and workflow (e.g., work phases, collaboration style, resulted categories), (ii) spatial layouts (e.g., general arrangement between and within clusters in the room), and (iii) spatial placement (e.g., placement of clusters related to room components and furnishing). Each of these categories was divided into several subcategories and discussed among authors then synthesized collaboratively and iteratively into higher-level findings through video coding.

3 OBSERVATION RESULTS

Based on our data analysis, we could identify several patterns and arrangements giving first insights about how users organize and place virtual content in relation to the physical environment in a collaborative AR space.

[1] https://spatial.io/

[2] Participants were instructed to remain 1.5m away from each other.

[3] from Kaggle https://www.kaggle.com/moltean/fruits [14] and https://www.kaggle.com/adithyaxx/the-comprehensive-cars-compcars-dataset [21]

Figure 2: The pattern of the final layout: (A) The *panoramic-strip* pattern of T3 less-furnished with fruits. (B) The *semi-cylindrical* pattern of T2 fully-furnished with fruits. (C) The *furniture-based distribution* pattern of T3 fully-furnished with cars.

To better understand the observed layouts and placement of the images in the card sorting task, we first give a brief overview of the resulting categories. The teams could freely organize and cluster the image datasets (i.e., no predetermined categories or a number of clusters) and create as many categories as possible; but they could not clone a image. The number of clusters varied between the teams and especially between the two datasets. For example, for the fruit dataset, about 14-25 clusters were created, while for the car dataset, there were about 23-36 clusters (except for team 4, which created only a few but larger clusters). For the fruit dataset, the teams often defined 1-2 main categories, such as image representation like "a single fruit" or "several fruits" (T1, T4), the "packaging type" (T3), or "fruits on plants" (T2, T3) are shown. Then they created 2-3 subcategories, e.g., based on "color of fruits" (T2, T3, T4), "type of fruits" (T1, T2, T4), or "type of plant" (T1, T2). In contrast, similar categories of the car dataset were chosen, but the choices as main or subcategories differed. For example, the "perspective of the car" in the image was the main category for T3 and a subcategory for T2 or the "type of car" (e.g., "sport car", "van") as main category for T4 and as subcategory for T2.

All teams used a workflow that began with a coordination phase (data overview and define main categories), followed by individual work (placing images in the main categories mainly using the ray-casting interaction) and then short repetitive discussion phases (clarify and refine image categories and subcategories).

3.1 Spatial Layout

We could observe three layout patterns for grouping and organizing the images of the datasets for the eight study sessions: (i) *panoramic-strip* (2x), (ii) *semi-cylindrical* (once), and (iii) *furniture-based distribution* (5x). Due to the initial layout of the image stacks evenly distributed in the area at the same height, to begin with, the teams used a panoramic-strip (T1, T3, T4) or semi-cylindrical (T2) arrangement to expand the image stacks and make a first pre-sorting into the main categories. Next, the teams started sorting by deciding on a main category, coordinating placement location, and assigning images from the image stacks to the clusters accordingly. For example, the fruit dataset was divided into "local fruits" and "non-local fruits" or "exotic fruits" and these groups were placed on the right or left side of the AR room (T1, T2). This assignment was often done in parallel, as users could remotely grab and place the images using the integrated ray-casting interaction without interfering with each other. The teams then reviewed the resulting clusters and discussed which further subdivisions or subcategories could be defined and how the placement within the cluster should be done. For example, T2 divided the "exotic fruits" into subcategories as "citrus" and "not citrus" and "color". Overall, this sub-categorization was iterative with close cooperation during this refinement phase. All teams used an iterative arrangement strategy.

In the **panoramic-strip pattern**, the images are mainly placed horizontally as a semicircle with the participant at the center, as shown in Figure 2(A). However, the distribution of the clusters is partly far apart, i.e., there are large gaps between the individual clusters and not always a continuous strip as in team 3. For two teams (T1, T4), we observed that starting from a panoramic-strip arrangement, they iterated and ended up with a placement of the groupings on two main sides. For instance, the final layout of team 4 (T4:less-furnished+fruits) is compact but spatially dense with two main sides of content, one at the front side tables and one over the whiteboard. Also, team 1 (T1:less-furnished+cars) used a very different spatial layout with two main sides: small clusters far separated on the left side and spatially dense, larger clusters on the right side.

In the **semi-cylindrical pattern**, the images are mainly arranged by using both horizontally and vertically axes (T2, T4). For instance, team 2 used this pattern in both study conditions. They mainly used the space from the floor to the top to form a semi-cylindrical structure without considering the space of the front side tables and the orange wall (T2:less-furnished+cars), see Figure 1(B). For the second condition (T2:fully-furnished+fruits), they used the semi-cylindrical layout in a more compact form, i.e., the space was divided into two main clusters and the respective subclusters were spatially very close together. This spatial density is probably because T2 has little movement and mostly stood at the front side tables. The final layout of team 4 (T4:fully-furnished+cars) resulted in a combination of a semi-cylindrical pattern and a furniture-based

Figure 3: The observed spatial placement for content arrangement: (A) The *orange wall* as a continuous area used by T4. (B) The *door area* used by T4. (C) T2 arranged a cluster of images above the *cabinet*. (D) T2 used the left side table's edge to divide two clusters. (E) A *free gap* between the front and side table, which was used by T3 for placement.

distribution of clusters, i.e., the image clusters were placed between the door area, above the side tables in front, across the corner to side tables on the left and leaving out the back side.

In the **furniture-based distribution pattern**, the images are mostly arranged in several separated clusters and subclusters distributed in space but guided by the real-world furniture (e.g., above or below the tables, aligned to the orange wall), see Figure 2(C). This furniture-based distribution pattern was often be observed in combination with the other patterns. Particularly in the refinement phase, the placement of the subclusters became more oriented to the furniture than to natural boundaries (e.g., walls) in the physical environment (e.g., T1, T2, T3).

Some teams also used the spatiality within a group to organize the content. We could observe a **top-middle-bottom pattern** where the subclusters within a cluster were separated along the vertical axis. For example, team 3 (T3:fully-furnished+cars) used it to organize the "car types" into "sport cars" (top), "normal cars" (middle), and "vans" (bottom) or team 1 (T1:fully-furnished+fruits) arranged the "type of growing" into "tree" (top), "bush" (middle), and "ground" (bottom). The subclusters within a cluster were rarely separated on the horizontal axis such as **left-right** (e.g., T1:fully-furnished+fruit for the subcluster "unpeeled vs. peeled"). In contrast, the horizontal separation into left-(middle)-right was used more for the between-clusters organization. Furthermore, we observed that some teams (T1, T2, T3) **overlapped** the images with similar or duplicate content for the purpose of organization.

3.2 Spatial Placement

To organize the various clusters, the teams used the physical environment for their content placement, specifically, (i) a usage of *vertical planes*, (ii) a *furniture-oriented placement*, or (iii) *other spaces* in the room for their cluster organization. For instance, available **vertical planes**, such as the *orange wall* (5x) or the *door area* (3x), were used as a continuous but defining space to form a cluster (T1, T2, T3, T4), see Figure 3(A) and (B). Here, the height range was also used for the subcluster arrangement (e.g., T1:fully-furnished+fruits). Few teams also used the *whiteboard* (4x, T1-T3 only with car dataset) or the *white wall* (2x, T2 and T3) between the whiteboard and the cabinet to place a cluster. Since the physical space here is relatively smaller, this was used less frequently and predominantly for small clusters.

For the **furniture-oriented placement**, the teams mainly used the *cabinet* and the *side tables* on the left side of the room and the front side. All teams (except T4) used the *cabinet* (5x) as an orientation for cluster placement, either placing the cluster directly above the cabinet (T1:fully-furnished+fruits, T2:less-furnished+cars) or using the geometry of the cabinet for the subcluster organization (T2:fully-furnished+fruits, T3:fully-furnished+cars), see Figure 1(C) and Figure 3(C). For instance, T3 arranged images of a cluster on an imaginary plane in front of the *cabinet* and used its geometry for their subclusters ("sport cars" above the cabinet, "normal cars" on top of the cabinet, "vans" on the cabinet doors). Furthermore, all teams mainly used the *side tables* on the left (8x, T1-T4) and partly on the front side (4x, T4 and T3) to arrange clusters above the edge of the table. Only T2 placed image clusters below the table and on the floor (T2:less-furnished+cars), see Figure 3(D). Due to the long side tables, several clusters were placed next to each other (e.g. T1:less-furnished+cars) or a larger cluster was arranged with subclusters (e.g., T2:fully-furnished+fruits, T3:fully-furnished+cars, T4:fully-furnished+cars).

We observed that all teams utilized the landmarks of the physical environment for their spatial placement. Specifically, the teams tended to use the natural edges, such as the surface of the table, the top of the cabinet, or the pencil tray of the whiteboard, to organize the clusters by separating clusters above and below this edge. For example, team 2 (T2:less-furnished+cars) used the left side table's edge to divide the top cluster "car perspective" between "white cars" (below the table) and "black cars" (above the table), see Figure 3(D). Team 3 also edited their final layout in order to not break the edge of the whiteboard with images (T3:less-furnished+fruits).

Another surprising observation was that some teams used **other spaces** in the physical environment, like *free gaps* (4x; T1, T3, T4) for specific placement of clusters, e.g., as Figure 3(E) shows, the left front corner between the two side tables. The *stone column* (4x) in the left back corner was also used as a natural cluster separator (e.g. T1:fully-furnished+fruits). Also, the perceptible deepening between the door area and the orange wall was used as a natural cluster separation (T1, T3). Here, the different depths of the room areas were also taken into account when arranging the images, e.g., images on the level of the orange wall were placed closer to the users than the images in the door area (T1:fully-furnished+fruits).

Furthermore, we could observe that the whiteboard area was also used as **temporary storage space** during the task (T4). Other temporary storage spaces (known from territoriality research) were used in the room center (T2, T1) or on the floor (T3). Basically, we observed that the furniture is primarily used as a placement reference. Also, most of the teams used the furniture for communicating the targeted position of images during the study (also noted in the interview by T1 and T3). We could not observe any differences in spatial layout and placement related to the dataset or room condition. Most of the teams (T1-T3) ignored the round table and the chairs in the room center and perceived them as obstacles in the room (e.g. walked around it or commented on it in the interview).

4 DISCUSSION AND FUTURE WORK

In the preceding sections, we have illustrated how users would place content based on the physical surrounding for a collaborative organization task. We found our participants took room and furniture settings into account when arranging AR content (e.g., P3: "[we used] the wall. We use this whiteboard as a special area for cars.", P2: "I think we mainly used the constituents of the room, partly side tables or the whiteboard."). However, we also observed unexpected behavior and placement during the experiment. For instance, the images in the final arrangement are all vertically placed despite the available horizontal surfaces. As one reason we suppose users prefer using ray-casting for interacting with images from the distance. And Spatial will automatically adjust the image orientation once selected by ray-casting. Another reason could be the nature of collaboration as users wanted to adjust the image orientation for a better visibility to the collaborator (P6: "The images could not be seen by the partner if one placed them horizontally on the table."). Finally, without the real-world constraints of gravity, users might prefer vertical placements of content for readability. Other observed patterns based on collaboration are: the use of temporary storage space, dividing the AR room into 2-3 areas at the beginning of the sorting task to support individual work, and using the furniture and room areas for communication and coordination.

We also noticed that the central round table was less used than we expected. Through the interview, participants explained that some physical settings are more intuitive to use, like walls and the whiteboard. In addition, an explicit visual cue attached to the round table would be helpful, for example, a virtual plane on the physical table as an anchor (P5: "[it] will be more apparent that it is also a usable space."). Besides, a corresponding interaction like snapping to the table would also encourage such a placement (as for example commented by T2 and T3). In summary, this feedback shows the value of our study and triggers several follow-up questions for further investigation.

In our future work, we are planning to run further in-depth studies in order to extract more representative and generic content layout patterns for several collaborative activities, thereby also involving users with little AR experience. In addition, we will take into account a high-level brainstorming task emphasizing the creative process, which helps shed light on the structure process of foraging and sensemaking. Moreover, since we currently focused on two-person collaboration, an extension to multiple people collaborating is worth considering, because it is more common in daily brainstorming and sensemaking activities. Furthermore, we believe that characteristics and the form factor of the physical surroundings could also be further investigated, since participants (P3-P5) highlighted their expectations with regard to be able to "snap" or "aggregate" content based on the type of furniture. With our work we hope to have made a first step to better understanding the usage of Augmented Reality for enhancing everyday collaborative workplace activities in real-world environments.

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