Documents in Your Hands: Exploring Interaction Techniques for Spatial Arrangement of Augmented Reality Documents

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Figure 1: (A) We conducted a study where participants proposed interaction techniques for arranging AR documents. Based on the findings, we introduce a design space, derive design implications, and illustrate use cases with a rapid prototyping system. These use cases include (B) affinity diagramming (classifying and clustering sticky notes), (C) document management (fanning out documents and enlarging one), and (D) graphic design iteration (brushing a row layout to compare variants).

Abstract

Augmented Reality (AR) promises to enhance daily office activities involving numerous textual documents, slides, and spreadsheets by expanding workspaces and enabling more direct interaction. However, there is a lack of systematic understanding of how knowledge workers can manage multiple documents and organize, explore, and compare them in AR environments. Therefore, we conducted a user-centered design study (N = 21) using predefined spatial document layouts in AR to elicit interaction techniques, resulting in 790 observation notes. Thematic analysis identified various interaction methods for aggregating, distributing, transforming, inspecting, and navigating document collections. Based on these findings, we propose a design space and distill design implications for AR document arrangement systems, such as enabling body-anchored storage, facilitating layout spreading and compressing, and designing interactions for layout transformation. To demonstrate their usage, we developed a rapid prototyping system and exemplify three envisioned scenarios. With this, we aim to inspire the design of future immersive offices.

CCS Concepts

• **Human-centered computing** → **Mixed / augmented reality**; **Empirical studies in interaction design**.

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spatial layout, content organization, interaction design, user-centered design, Mixed Reality

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1 Introduction

Mixed or Augmented Reality Head-Mounted Displays (MR or AR HMDs) are extending our office workspace. In the future, documents with texts and images, along with application windows, will no longer be limited to rectangular monitors. Instead, they can be freely placed anywhere in the environment as holograms, fully leveraging the infinite display space. Consequently, various types of virtual documents have been investigated in immersive environments, such as office papers [72, 89], brainstorming notes [21, 93], design sketches [47, 116], and data diagrams [62, 76, 77]. As immersive environments become more accessible and the prevalence of holographic documents grows, there is an increasing demand for MR applications to support users in organizing and arranging multiple documents.

We envision better space usage in such MR-enabled offices facilitated by direct and far-reach interaction. Users can move freely throughout their offices, strategically placing holographic documents anywhere and organizing them into various spatial layouts according to their specific goals. While *Immersive Space to Think* [75] systems have already demonstrated the potential for sensemaking in immersive environments, we believe that users can benefit from interacting with digital documents in a natural and intuitive way. For example, they can push virtual documents into a stack on the table, flick their wrist to fan them out, or toss them onto a physical whiteboard as a grid, leveraging familiar organization methods from the physical world [53].

However, designing such interactions is inherently challenging [28, 29, 58]. Organizing virtual documents in 3D space necessitates rethinking interaction techniques for multiple objects, such as selection and manipulation. These interactions must support various spatial layouts based on user intentions and layout characteristics, facilitating document placement in MR environments with complex geometric and semantic contexts. Therefore, exploring how users would articulate space usage and interact with document collections is essential. These insights are vital for guiding the design of immersive applications that facilitate the organization of virtual documents.

To address this research need, we conducted a user-centered design study in a simulated office environment (see Fig. 1A). We designed a *"priming & production"* study procedure (informed by [90]), in which 21 participants engaged in 14 different tasks across 22 spatial document layouts, resulting in 790 observation notes. Through thematic analysis, we discovered various interaction methods to translate, aggregate, distribute, transform, and navigate document collections. Furthermore, we identified participants' general attitudes and rationale based on post-study interviews.

Building on our study results, we propose a design space describing essential attributes for document organization in immersive environments. We derive design implications to inform the design of future MR systems, such as anchoring documents to bodies for temporary storage, enabling the adjustment of layout compactness, and designing interaction for layout transformation. To facilitate practical interaction design, we developed a rapid prototyping system, enabling AR interaction mock-ups with keyframe animations. We also present envisioning scenarios (see Fig. 1B-D) to demonstrate the applications of our findings. With our work, we aim to inspire and guide designers by showcasing the potential and richness of spatial interaction for document organization and setting the foundation for future immersive offices.

To sum up, our main contributions are:

- Empirical insights of user action patterns, strategies, and rationales for arranging virtual objects based on a user-centered design study (N = 21).
- A design space and seven design implications to guide the creation of future immersive systems handling document organizational tasks.
- An open-source rapid prototyping system to illustrate three imaginative scenarios for inspiring future applications.

2 Related Work

Organizing digital content into structured layouts is essential in Human-Computer Interaction (HCI). This topic encompasses the appearance of layouts and the methods users use to create and manage them. To provide a comprehensive overview, we categorize the related research by device types. This includes flat screen interfaces (Sec. 2.1), cross-device environments (Sec. 2.2), and immersive environments (Sec. 2.3).

2.1 Flat Screens

For 2D desktop interfaces, various techniques have been explored to organize multiple views [110]. These approaches include spatial layouts such as piles [84, 104], overlaps [54], and Mosaic [123]. Interaction techniques involving trays [8], bubble [124] metaphors, and proximity-driven approaches [22], have been also proposed. For instance, *PILING.JS* [69] summarized user goals and presented piling metaphors for organizing data collections (small multiples). 3D desktop interfaces have explored spatial metaphors like gallery rooms [103], mountain landscapes [3, 102], flows and loops [94], and information spaces [23, 24]. These can be interacted with by natural gestures to highlight, scroll, and expand documents [48, 66], indicating the potential to extend beyond flat screens. However, these works were designed for confined 2D screens, where users are inherently restricted and isolated.

Interactive surfaces like display walls and tabletops provide increased space, allowing diverse organization methods. For instance, *Space to Think* [4] was proposed to analyze documents on a large display to externalize cognition. Large hand gestures [27, 57] and physical navigation (i.e., walking) [5] were suggested to interact with documents. Moreover, techniques for structuring multiple contents on tabletops, such as alignment tools [37], grids and guides [35], and pen strokes [36], have served as inspiration. Particularly, *Rock & Rails* [126] introduced fist ("Rock") and flat-hand ("Rail") gestures to define and manage document layouts. *BumpTop* [1] proposed a realistic interaction style that incorporates the knowledge of how objects move and change in reality into the interface design, including piling, fanning out, and page leafing. Likewise, interactions like sliding with fingertips, gathering with entire hands, and shoving with real paper cards have been explored [128].

Considering the larger space, natural interaction, and inclusion of real-world surroundings, it is promising to further extend document organization into MR environments. However, as users also manipulate digital objects fundamentally differently than their physical counterparts [118], AR documents should not simply be treated as digitized papers. Instead, the exploration of new design possibilities beyond realism and known affordances is also needed.

2.2 Cross-Device Environments

Multiple devices can be combined into cross-device environments, creating flexible workspaces for distributing and engaging with digital content. Comprehensive surveys have summarized the taxonomies and practices of these environments [14, 133]. Specifically, homogeneous devices, such as multiple desktop monitors [73, 133] or multiple handheld devices [85], can be united. We draw inspiration from interaction techniques for arranging and transferring digital documents across devices, such as tray tools [136], hand gestures (swiping, flicking, and pick-and-drop [99, 129]), spatial device gestures like tilting [85], and physical-object-based interactions like slamming on tables to broadcast [42].

Heterogeneous devices with distributed roles can also be combined. Examples include pairing desktop monitors with wall displays [50, 83] and handheld devices with tabletops [98, 135] or with wall displays [61]. Small personal devices often function as accessible workbenches for temporary storage and manipulation, while their physical form can also act as spatial pointers on larger devices. In contrast, larger devices are primarily used for content placement. For instance, phones can serve as personal proxies to spread documents on wall displays based on movement [61].

However, despite the tangibility, the physical nature of devices largely limits the possibilities. In contrast, users can customize AR documents on demand, adjusting their scale and placing them anywhere in immersive environments, creating designated workspaces.

2.3 Immersive Environments

In immersive environments, holograms are often organized by users into various spatial layouts, such as planar [62, 109], circular [75, 77], or environment-based [21, 75]. To support layout design, *Ethereal Planes* [30] presents a design space focusing on the placement of AR content around the user. Likewise, AR content can be directly attached to the user's body [43]. However, designing content organization systems that fully leverage 3D space remains challenging. Various factors can influence layout preferences, such as content characteristics (e.g., number and geometry) [62, 77], user tasks, and workflows [78, 109]. Moreover, since multiple AR documents can be composed spatially in a variety of ways, supporting their organization process is more complicated.

Holograms can be integrated into real surroundings [63, 127]. However, designers have to consider factors like visual salience [32] and spatial and semantic association [26, 31, 71]. Physical surfaces, such as walls [31], ceilings, and floor [107] can be the anchors for content placement [92]. Physical objects such as furniture have been utilized for organizing virtual documents [16, 81] or referring to associated visualizations [63, 82]. The presence of other persons also influences content placement, such as around [106] and between people [47]. While the inclusion of real-world elements expands document placement options, it also increases the complexity of designing systems for content organization. It is crucial to understand where to organize documents, when to transition them, and how to manage these transitions.

AR applications can support content arrangement by suggesting and refining object placement through methods such as surface detection [87, 92, 121], object auto-clustering [117], or object relocation [80, 91]. Full automation that minimizes manual effort has also been explored, like adaptation to the physical environments [19, 38, 97], user context [34, 60, 80], or original layouts [20]. However, as adaptation results can deviate from actual intentions, users reported preferring to retain control [80, 117].

Various interaction techniques have been studied for manually arranging virtual content [9, 15, 115]. Those include freehand gestures [80], gaze [64], body or proximity [40, 76], and extra devices [101, 111]. For instance, *FingerSwitches* [96] is a pinch-gesture-based technique, supporting the transitions of UI between static, dynamic references, and users themselves. In addition, symbolic gestures like *Plane, Ray, and Point* [46] can set shape constraints, while tools like a handlebar metaphor [113] and 3D grid [7, 111] can be used for manipulation and alignment. To organize multiple virtual notes, a set of natural interactions was proposed [68], including snapping notes on the clipboard, sweeping them to align, transferring bulk notes by a sieve, and crumbling the clipboard for deleting. Moreover, users' bodies can store content, including on-body areas (e.g., wrist [80]), around-body space (e.g., waist [55, 76]), and around foot areas [76]. Retrieval can be facilitated by pull-out gestures [80], contextual menus [55], and feet [76].

Despite these advancements, prior work primarily focuses on specific interaction methods and particular use cases. Given the sophisticated nature of document organization in 3D space, there is a lack of coherent perspective on how document spatial layouts and placement in mixed-reality environments should adapt through interaction methods to suit users' varying goals and intentions.

3 User-Centered Design Study

Our goal is to understand document organization in immersive environments and inform the design of future MR systems. We focus on user interactions with multiple virtual documents for organization in AR environments but also consider document exploration and comparison as the final goals of such organization. To this end, we conducted a user-centered design study to elicit interaction techniques. We investigated fundamental tasks reflecting core activities of everyday document arrangement. Data was collected and analyzed both quantitatively (open-coding) and qualitatively (thematic analysis). Detailed protocols, raw data, and analyses are provided as supplemental material.

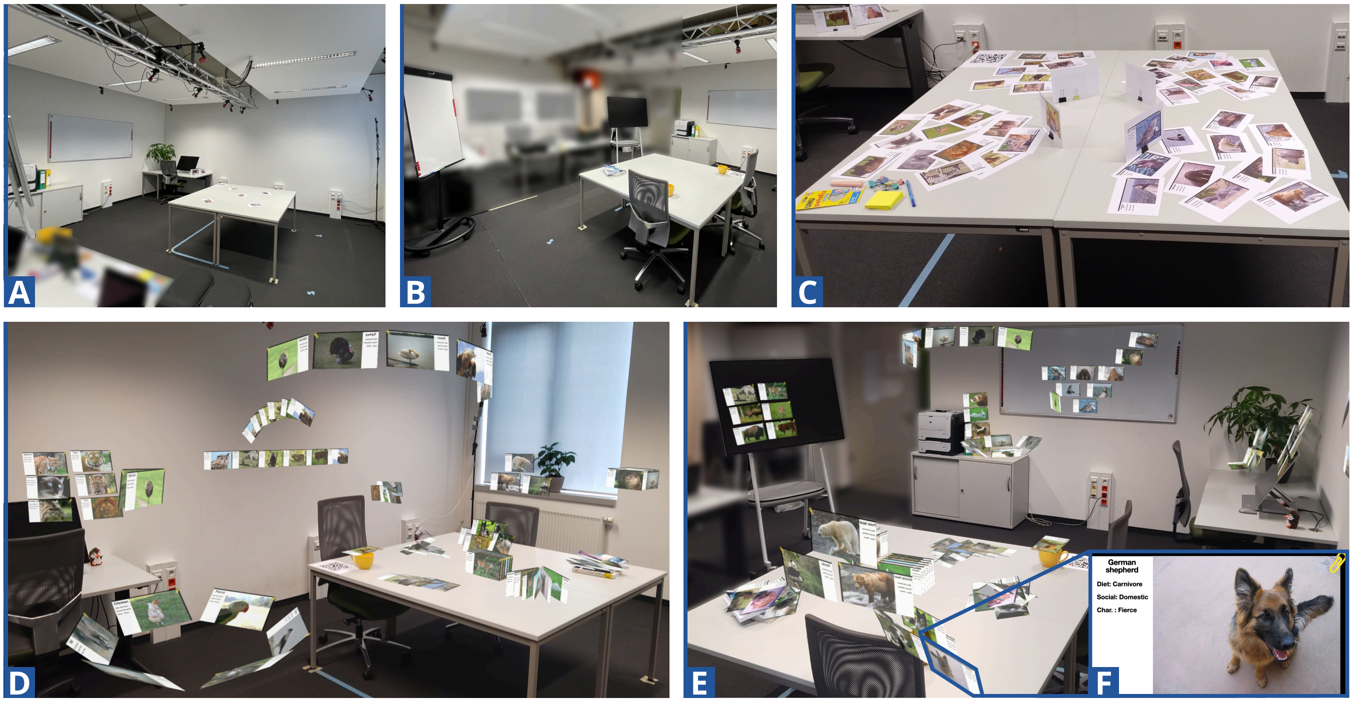

Figure 2: Overview of the study environment. (A+B) show the initial state of the study environment for the *priming* and *production* phases, respectively, captured from different angles within the same space. (C) presents layouts created by a participant during the context priming. (D+E) show different views of the predefined layouts in the AR prototype during the *production* phase. (F) shows one of the documents used in the study (Dog image ©Perfect Zero, CC BY 2.0).

3.1 Study Design and Rationale

To investigate document organization activities and generate techniques for arranging virtual documents in AR, we examined the transformation of document layouts (as "referents"), the techniques to achieve these transformations (as "symbols"), and the relations between transformations and tasks. We opted for a user-centered, open-ended procedure by only providing various starting layouts, aiming to reach a high saturation and richness of elicited techniques. This differs from the classic elicitation studies, where referents' start and end states are mostly clearly defined.

We created an exhibition scenario where participants were asked to prepare a presentation with given documents. We leveraged a set of common document organizational tasks (informed by [69]) to closely observe how participants would organize paper documents or AR documents. To counteract legacy biases, we employed priming and production techniques [90]. Specifically, we applied three types of priming: context, creativity, and environmental priming. With context priming (similar to [100]), we used paper documents to foster an understanding of the document organization scenario and its requirements. We implemented creativity priming with sci-fi movies to inspire designs based on new form factors [2]. Finally, we adopted environmental priming, which involved locating related objects to counter unfamiliarity and raise awareness of the environment. During the elicitation with the production method, participants were instructed to propose as many techniques as possible with AR HMDs for organizing holographic documents. A pilot study (N = 3) was conducted to test and refine the procedures, including improving instructions.

3.2 Study Materials & Apparatus

A simulated office environment was prepared for the study, incorporating various working documents, document layouts, and an AR prototype.

Study Environment. The study environment resembled a typical office space, measuring 4 m × 5.9 m, with objects commonly found in an office, including a large meeting and working table (1.6 m × 1.6 m), a desk with a desktop PC, two whiteboards of different sizes, a vertical interactive surface, a cupboard, and several plants. For context priming, participants were supplied with additional office materials, such as sticky notes, pens, and binder clips. During the *production* phase, additional objects like a coffee mug and books were placed on the large table to simulate an active working environment (see Fig. 2B, D+E). Two experimenters were in the same room adjacent to the study area to moderate and observe the participants.

Documents and Layouts. Participants were provided with several documents to organize. Each document described an animal with three aspects (similar to [81, 125]): name, picture, and three attributes (diet, social, and character). For example, "German Shepherd: Carnivore, Domestic, Fierce," as shown in Figure 2F. We prepared 50 paper documents (A5, 21 cm × 14.8 cm, see Fig. 2C) for the *priming* phase and 110 virtual documents (24.8 cm × 14 cm, see

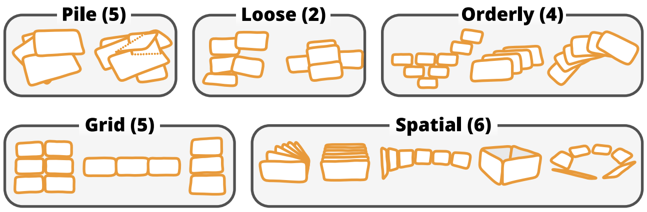

Figure 3: Five categories of predefined layouts used in the *production* phase of our study, with the numbers in brackets indicating the number of layouts used from each category.

Fig. 2D+E) for the *production* phase. These virtual documents were predefined in 22 different spatial layouts based on factors such as the number of documents, dimensionality, order, compactness, and overlap. We categorized them into piles, loose, orderly, grid, and spatial layouts (see Fig. 3 and Fig. 2D+E). The documents were fixed in size and positioned either in mid-air or associated with physical objects such as whiteboards or books.

AR Prototype. A lightweight AR prototype was developed for rendering virtual documents in the *production* phase (see Fig. 2D+E), using the Mixed Reality Toolkit (MRTK)[1], Unity 3D[2], and C#. The prototype was deployed on a Microsoft HoloLens 2. A QR code on the table was used to align the AR scene with the study environment, allowing the same application to run on different HoloLenses (for participants, experimenters, and the recording camera). To minimize the influence of interaction techniques and prompt participants to focus on ideation rather than implementation, the virtual documents presented were view-only, without manipulation capabilities.

3.3 Participants

We recruited 21 participants (7 female, 13 male, 1 non-binary) via word-of-mouth and email. The average age was 26 years ($M = 26.19, SD = 4.42$). Participants were current or former students from the local university, majoring in various disciplines like architecture, medicine, psychology, software engineering, information science, and computer science. On a five-point scale, participants reported organizing various types of content relatively strictly ($M = 3.76, SD = 0.70$) on a nearly daily basis ($M = 3.86, SD = 1.01$). They did this more frequently for digital ($M = 3.67, SD = 0.66$) than for physical ($M = 2.81, SD = 1.08$) documents and regularly revise their arrangements ($M = 2.62, SD = 0.74$). Most participants had limited experience with AR ($M = 2.24, SD = 1.18$) or VR HMDs ($M = 2.48, SD = 1.12$) and minimal experience with freehand interaction ($M = 1.81, SD = 0.93$). Participants were compensated with 25€.

3.4 Study Tasks & Procedure

The study was conducted by two experimenters and involved five steps: (1) Welcome and introduction; (2) Pre-study questionnaire on demographic information, current organization practice, and immersive technology literacy (see Sec. 3.3) and consent form; (3) Three *priming* procedures; (4) Technique *production* with premade AR document layouts; (5) Post-study interview and conclusion. Each session lasted approximately 130 min (M=128:40 min, -SD=13:26 min).

[1]https://github.com/Microsoft/MixedRealityToolkit-Unity
[2]https://unity.com/

Organize

01 - Cluster Documents
02 - Add a Document to a Group
03 - Remove a Document from a Group
04 - Move a Document to another Group
05 - Move whole Group
06 - Merge Groups
07 - Split Groups
13 - Store to Temp. Workspace
14 - Annotate

Explore

08 - Preview a Group
10 - Search Document from Environment
11 - Search Document from a Group

Compare

09 - Overview a Group
12 - Sort within a Group

Figure 4: Tasks used in the study, with the numbers indicating the execution order. These tasks are categorized into organizing, exploring, and comparing.

Priming. It consisted of three priming procedures. First, context priming involved participants organizing physical documents for an exhibition without specific criteria. Initially, they freely organized 25 documents presented as five stacks on a table. After 10 min, 25 additional physical documents were distributed in 5 stacks throughout the study environment, simulating daily situations where users often have to consider new documents and work iteratively. After another 10 min, participants briefly presented their classifications and reasoning. During the study, participants were instructed to think aloud and freely rearrange the environment if they desired. Lastly, an experimenter asked the participant to recall and demonstrate the organization process with physical documents based on a set of organizational tasks (see Fig. 4 and supplementary material). This phase lasted approximately 41 min (M=40:59 min, SD=3:52 min).

Next, creativity priming was executed. Participants were seated to reduce fatigue and watched a 4:23 min video featuring scenes from sci-fi films (e.g., Avatar and Iron Man) depicting characters interacting with holograms. Lastly, environmental priming was conducted to familiarize participants with the study environment and examine the use of physical objects for organization. An experimenter orally listed various objects, and participants located them in the room. The entire *priming* phase lasted around 50 min (M=49:36 min, SD=3:50 min).

Production. The *production* phase involving AR HMDs consisted of two stages. Participants first explored and examined the AR environment with 110 holographic documents arranged in predefined layouts. They were then asked to propose techniques for a set of organizational tasks (see Fig. 4) without considering technical limitations. Participants could verbalize, act out, or sketch (on paper) their proposed techniques. To fully explore different arranging techniques and achieve high saturation and richness of results, participants were asked to produce as many techniques as possible for each task. To facilitate ideation and inspire diversity, participants were encouraged by the experimenter to consider different situations. They were motivated to freely move around in the study environment while considering how to arrange documents in

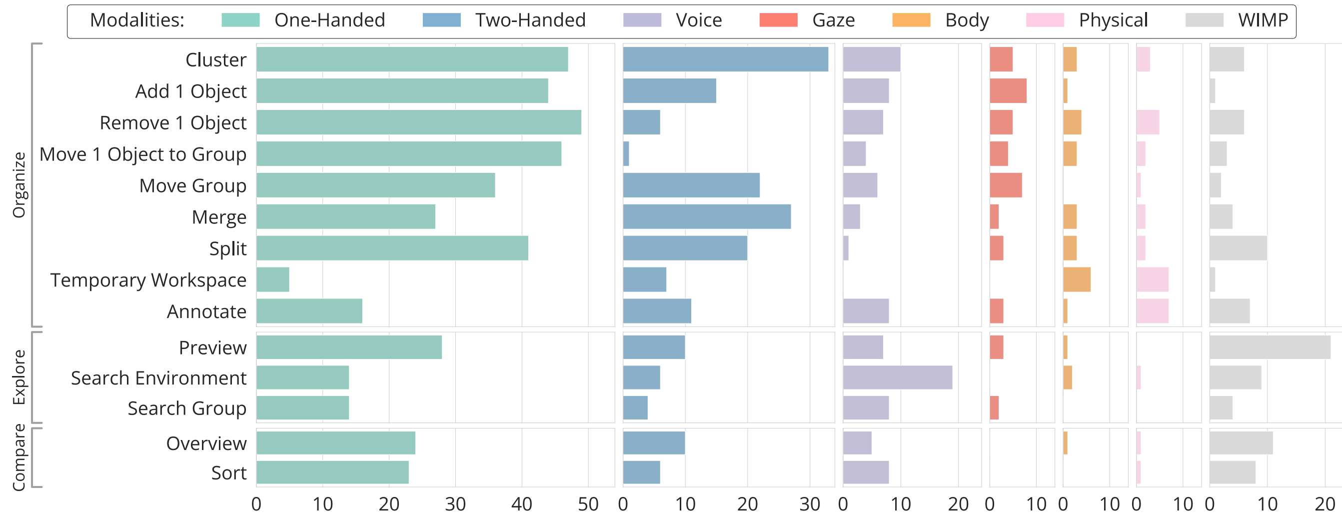

Figure 5: Occurrences of proposed techniques categorized by input modalities across study tasks. Hand gestures, including both one- and two-handed, were predominant across all tasks. Voice input was mainly used for search tasks. Gaze, body, and physical-object-based inputs did not show a clear pattern, while WIMP-style interactions were mainly used for previewing.

varied layouts (i.e., referents, see Fig. 3) and with different interaction distances to those layouts (far vs. close) until no further ideas can be proposed. The phase lasted around 63 min (M=62:28 min, -SD=9:29 min).

3.5 Data Collection & Analysis

We followed the principles of semi-structured qualitative studies [11] for data collection and analysis. Details of study documents and data can also be found in the supplementary material.

Data Collection. An iPhone, an iPad Pro, and a camcorder were used to video record user behavior, alongside observation notes taken using a semi-structured protocol. During the *production* phase, up to two HoloLenses were used to record participants' descriptions of techniques in the AR environment. Finally, a 10-minute semi-structured interview was conducted to probe participants' overall attitudes. The interview covered topics such as general impressions, media affordance (*"What is the difference between working with paper documents vs. holographic documents?"*), opportunities (*"What is the biggest problem of current document organization workflows, and would MR help?"*), and visions (*"Can you imagine a future MR office, and would you use it?"*). Participants were also asked additional questions informed by the study notes, regarding arranging strategies and recurring themes during the study.

Data Analysis. The analysis involved extracting and classifying the proposed techniques. Observation notes taken by two experimenters were digitized. A third author reviewed and partially coded video recordings to verify and supplement the notes. Three authors then thoroughly reviewed the notes with the support of videos to remove repetitions and refine descriptions, resulting in a total of 790 notes. These notes were analyzed using thematic analysis [13], categorized into two main themes and multiple sub-themes that evolved during classification (see Sec. 4). All authors discussed the results and cross-checked them together. The process was iterative until a consensus was reached. Finally, one author transcribed and analyzed interview comments via thematic analysis.

4 Results

We present the study results in this section, beginning with an overview of the descriptive statistics (Sec. 4.1). We then delve into the observed organization strategies and summarize the patterns identified (Sec. 4.2). Lastly, we illustrate participants' attitudes and rationales as revealed through the interviews (Sec. 4.3).

4.1 Descriptive Statistics Overview

From the collected 790 observations, participants proposed an average of 37 techniques ($M = 37.62, SD = 2.48$). We observed a slight, gradual decrease in the number of proposed techniques for each task during the *production* phase, likely due to the saturation of answers. In the following, we summarize the quantitative aspects of proposed techniques (see Fig. 5), providing an overview regarding *workspace*, *layout manipulation*, and *interaction modalities and styles*.

Workspace. Participants preferred placing or anchoring documents in relation to specific locations in the immersive environments. These locations included the general environment (3.80%) like ceiling and floor, specific objects (3.29%) like tables and whiteboards, or participants' bodies (22.78%). Documents could be placed on (13.92%), near (12.66%), or far (1.27%) from these anchors. During the tasks, documents were frequently moved between different anchors or workspaces (15.32%). Interestingly, detour transitions between workspaces (10.38%) were identified, where participants often moved documents close to themselves (near or on) before relocating them to the desired destination.

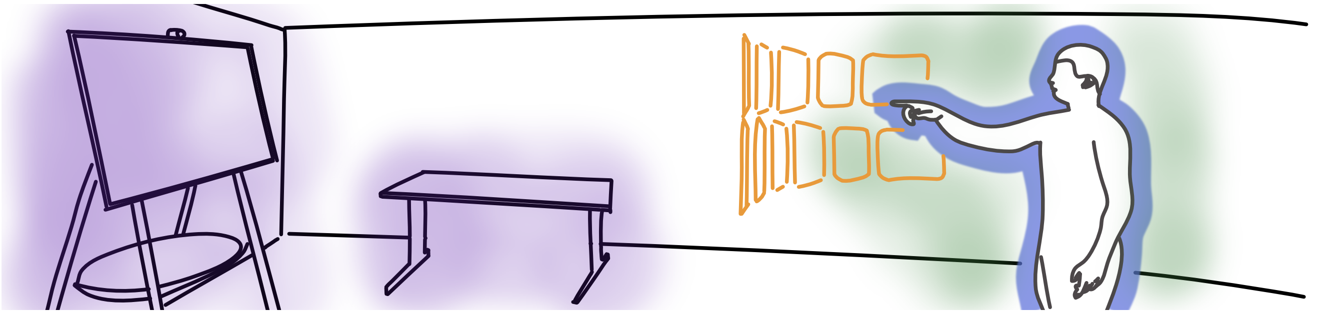

Figure 6: Observed workspaces in the study, including (1) *body-centric space* consisting of *on-body space* (in blue, the immediate space around the user) and *arm-reach space* (in green, within arm's reach), (2) *physical environment* and *real objects* (in purple), and (3) *open space* encompassing the remaining surrounding area.

Layout Manipulation. Participants were asked to imagine working with documents for study tasks like aggregating, merging, and splitting. However, additional organizing actions were observed for document groups throughout the study. Those include transforming (11.27%), storing (7.34%), compressing (5.70%), and spreading (10.25%) a layout and its documents. For instance, compressing a group (total of 45 instances) was performed to help move a whole group (14/45), cluster documents (9/45), or merge groups (6/45). Likewise, spreading a group (total of 81 instances) was performed to cluster documents (15/81), split a group (11/81), or preview (14/81) and overview (15/81) within a group.

Interaction Modalities and Styles. Observed interactions can be categorized into various input modalities (see Fig. 5), including hands (74.93%), voice (11.90%), gaze (5.32%), body (3.54%), physical objects (4.18%), or using WIMP elements (11.77%). We differentiate between one-handed (52.41%) and two-handed (22.53%) interactions. The latter was more common in complex tasks involving document groups. Participants frequently combined multiple modalities for specific interactions (21.91%, 173 instances), either via simultaneous use or in short succession. For instance, hands were often used in combination with WIMP elements (63/173), gaze (26/173), or physical objects (22/173). Participants showed a balanced preference for interactions within arm's reach (57.59%) and at a distance (45.57%), with occasional transitions between near and far (5.44%). We also identified distinct interaction styles and behaviors, including drawing (9.62%), typing (5.32%), acting (1.52%), and using out-of-context metaphors (6.96%). Our 21 participants regularly employed various metaphors, such as beckoning a document closer (12/21) and sending or throwing it away (17/21). Other examples included using a virtual fishing rod (2/21), a Spiderman gesture to select documents and pull them closer (P10), and a finger pistol gesture to shoot at a document for removal (P10).

4.2 Strategies and Patterns of Document Arrangement

Our thematic analysis revealed two main themes: *workspace* and *layout arrangement*. We first describe AR workspace characterization (Sec. 4.2.1) and document transition (Sec. 4.2.2). Next, we summarize group creation (Sec. 4.2.3), layout transformation (Sec. 4.2.4), and inspection and navigation (Sec. 4.2.5). We also discuss observed interactions (Sec. 4.2.6).

4.2.1 Workspace Types. *Workspace* refers to user-defined areas for engaging with virtual documents, including body-centric, physical-environment-centric, and open workspaces (see Fig. 6, aligned with [30, 65, 76]). The last was often used to place arranged documents after manipulation without anchoring to users or objects.

Body-centric. Participants took themselves as a reference to align and position digital content, either directly on bodies or within arms reach. **(1) On-body areas** represent the direct extensions of the body, such as hands (P12) or clothing pockets, like shirt pockets (P15, see Fig. 11A) and pants pockets (3/21). These areas were often used to *store* and *retrieve* documents, acting as *"virtual containers"* (P12, P21). Stored documents can be visible like thumbnails (*"lapel pins"*, P20) while being accessible from the arm (3/21), the fingertips (P2), or particularly the non-dominant hand (10/21). This facilitates *translating* groups while walking (3/21) or preparing for *layout transformation* (see Sec. 4.2.4). **(2) Arm-reach space** can serve as a workbench to directly interact with multiple documents in layouts, such as *planar* (P10, P11) and *circular* (3/21). Similar to on-body areas, documents can follow users dynamically (P14, P18).

Physical-environment-centric. Physical surfaces and objects were used to arrange documents. **(1) Vertical and horizontal surfaces**, such as walls (3/21) or a table (4/21), were often used to present grouped content. The center of the table assisted in document overview (3/21) and manipulation (2/21). Other parts of the table were used for temporarily *storing* documents for later *retrieval*, including the corners (P2) or imaginary drawers above or below its surface (P9). Moreover, the floor was used to store groups (P12), and the ceiling was suggested for hanging UI elements like a search bar (P6). **(2) Objects**, including tables, were used to locate, orient, and memorize virtual documents in the environment (4/21). They also served as proxies for document arrangement, such as *translating* documents with a whiteboard or a physical folder (P10, see Fig. 11B), pointing to documents with the tip of a pen (P4), and aligning documents with cabinet's edges (P10).

4.2.2 Workspace Transition. Participants transitioned documents between workspaces using two main strategies: *fetch and assign* and *pull and push*, for moving documents either close or distant.

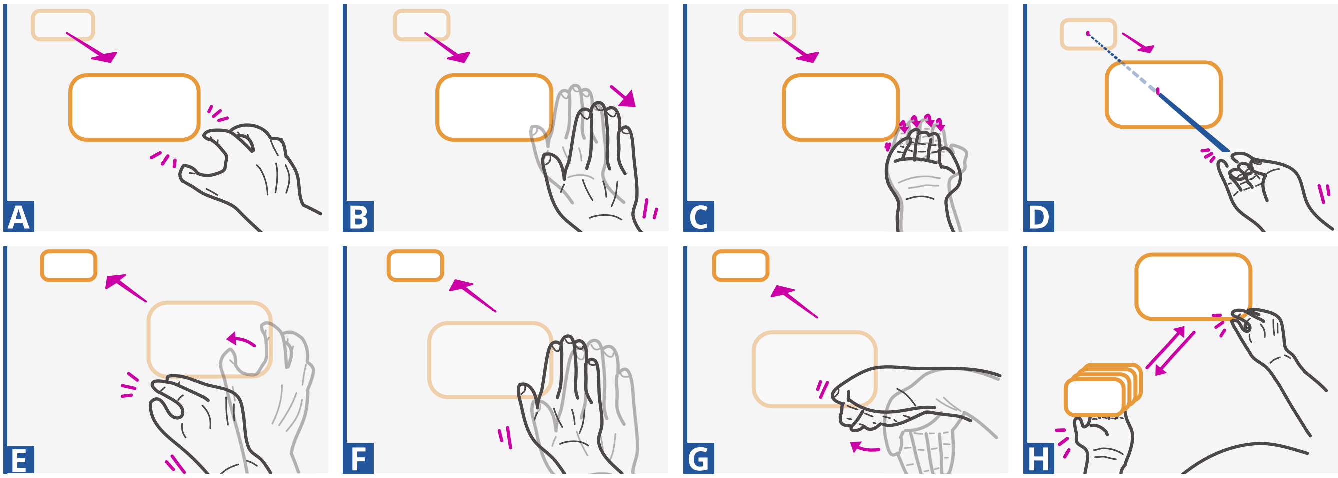

Figure 7: Identified interaction pairs for transiting documents among workspaces, including (A+E) grasp and throw, (B+F) attract and push, (C+G) "come to me" and "go away," (D) Spiderman superpower, and (H) fetch and assign.

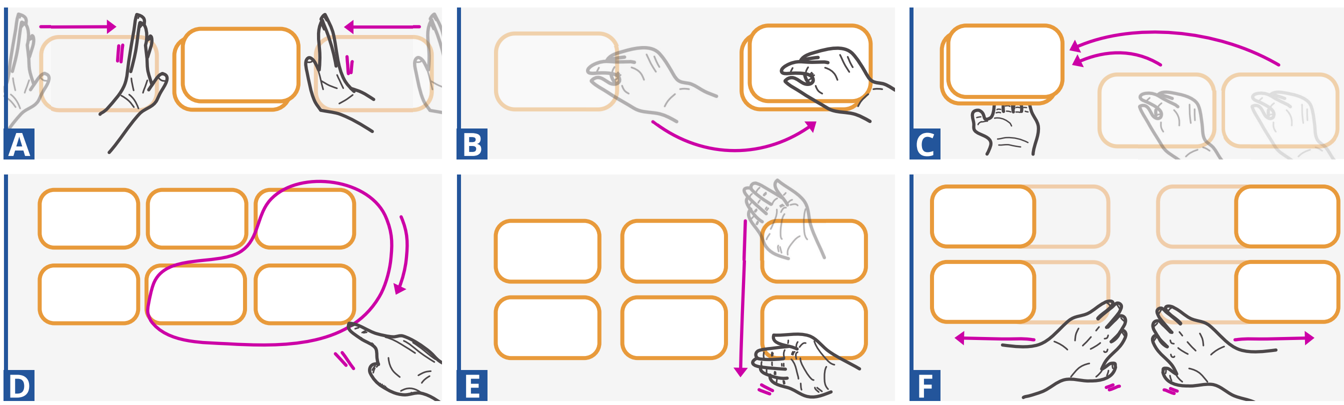

Figure 8: Identified interactions for merging or splitting groups: (A) colliding two groups, (B) overlapping one to another, (C) collecting to a shared place, (D) lasso selecting to split, (E) slicing apart, and (F) tearing apart.

Fetch and Assign. Participants moved documents from *arm-reach space* to *on-body areas* for temporary storage. This involves actions such as putting documents into a pocket (P19) or snapping them to the fingertips (6/21) to *translate* them somewhere else after walking there. Bi-manual interaction was common (6/21), where one hand was used to grab and the other to cluster documents (see Fig. 7H).

Pull and Push. This approach involved *transitions* between *arm-reach space* and areas farther away. These include **grasping and throwing** (6/21) documents from a distance to the target workspace (see Fig. 7A+E), using an imaginary vacuum or air blower to **attract and push** (5/21) documents across workspaces (see Fig. 7B+F), or performing **social gestures** (8/21) such as curling fingers to bring documents closer (i.e., "come to me") or moving one hand to send documents away (i.e., "go away") (see Fig. 7C+G). Additionally, participants **caught and retrieved** documents by using imaginary tools like a fishing rod, fishnet, or Spiderman superpowers (P10, see Fig. 7D).

4.2.3 Group Management.

The second theme involves user interactions with document groups and their *layouts* for organizational *tasks*. We first describe how groups were created from individual documents or from existing groups.

Grouping Documents. Groups were defined based on the spatial distance between documents, through placing documents close together in succession (3/21), shoveling them using both hands and arms (P16), or squashing them between hands (4/21). Resulting layouts included *collages* (P16, P19), *grids* (3/21), *piles* (3/21), and *stacks* (4/21).

Merging Groups. A group can be created by *merging* existing groups via **(1) colliding** (see Fig. 8A) two groups together with both hands, either slowly (6/21, see Fig. 11G) or fast like clapping (4/21). Other methods include hugging (P19), drawing a perspective lasso (P20), or symbolic gestures like crossing two hands (P3, P7). **(2) Overlapping** involves grabbing and releasing (12/21), pushing (P14, P18), or throwing (4/21) one group in another (see Fig. 8B).

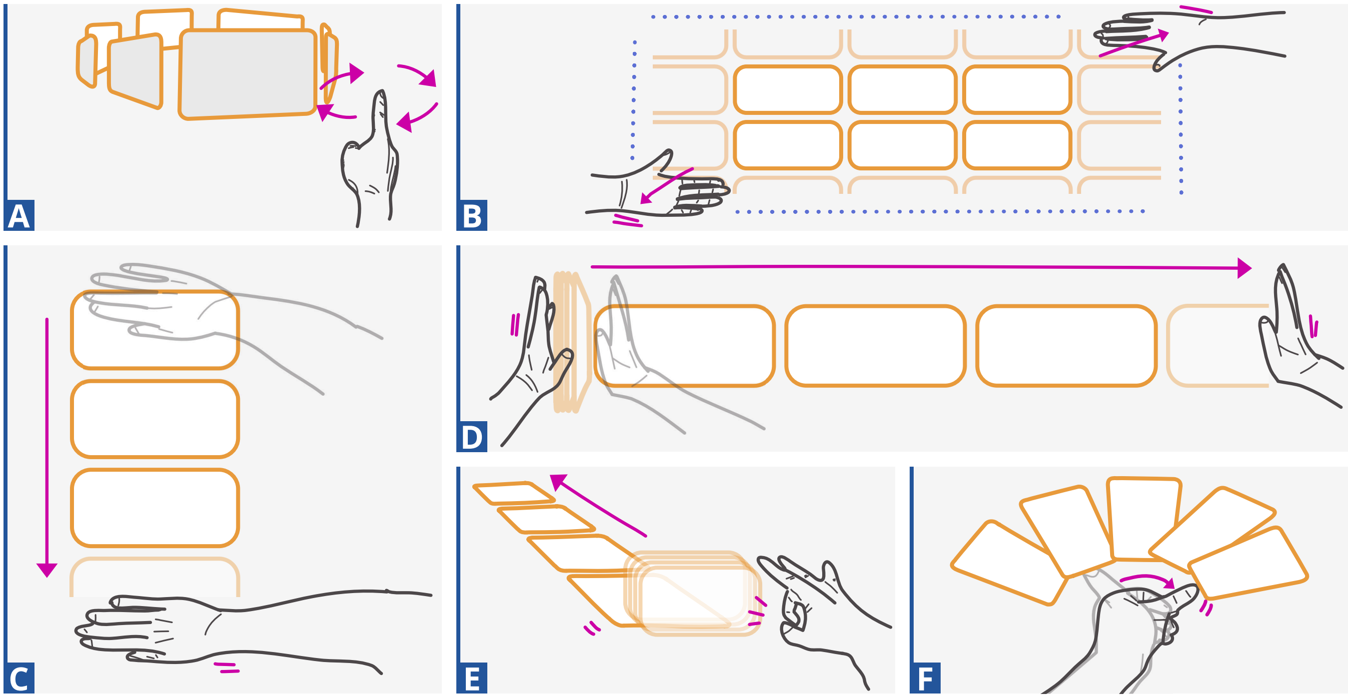

Figure 9: Identified interactions for transforming document layouts, including (A) symbolic drawing, (B+D) frame drawing, (C) brushing, (E) flicking, and (F) fanning gestures.

Through a **(3) temporary mediator**, participants first collected targets first on the left hand (3/21), fingers (P12), or physical objects (folders, P10) before merging (see Fig. 8C).

Splitting Groups. Splitting groups involves **(1)** moving documents **one-by-one** from one group to another by tapping (11/21), pointing (3/21), or flicking (4/21). **(2) Multi-selection** involves selecting and moving documents by tapping (5/21), scooping out (P11, P18), or lasso selecting (5/21, see Fig. 8D). **(3) Slicing** involves drawing separation lines directly in the layout (6/21; see Fig. 8E and Fig. 11H) or using a scissor gesture (P20-21). **(4) Tearing apart** involves using both hands to separate an already spatially ordered group, like opening a window (5/21; see Fig. 8F).

4.2.4 Layout Transformation. While compressing a layout facilitates group manipulation, spreading enhances the visibility and accessibility of documents within a group. These transformations can also draw on either the desired layout, the source layout, or a combination of both – the source layout infers potential interaction methods, while the target layout determines the extent and scale of interactions (10/21, e.g., see Fig. 9F "fanning" and Fig. 11F "pulling").

Compressing and Spreading Layouts. Participants often adjusted the spatial distance between documents. By squashing the borders, sparse layouts can be **(1) compressed** into *stack* (8/21), *poker stack* (5/21), or *thin stack* (P13, P15). This could increase group coherency and facilitate batch operations like *translation*, *transformation*, and *storage.* In contrast, compact layouts were often **(2) spread** out into *grids* (8/21) for overview and inspection, enabling precise operations like multi-selection (7/21), as sparse layouts enhance the visibility and accessibility of individual documents.

Result-layout-oriented Transformation. Participants frequently used their hands and arms to spatially "draw" the shape and scale of the desired layout. **(1) Symbolic drawing** was used to define the general shape of the target layout. To create circular layouts, for instance, P20 moved their finger *"like a magic wand"* in a circle (see Fig. 9A) while P10 drew a circle around their waist. **(2) Frame drawing** was used to indicate the scale of the target layout. For instance, moving hands apart horizontally (P15, see Fig. 11C) or diagonally (P18) determined the dimensions of *grids* (see Fig. 9B). Likewise, P18 performed an "accordion gesture" (see Fig. 9D and Fig. 11D) to create a *row* where the distance between both hands defines the width. **(3) Brushing** was observed to describe the target layout's shape and scale with the trace of hand movement. Examples include drawing a line with a flat hand to define a *column* (P16, see Fig. 9C), a semi-circle for *circular stripes* (P7, see Fig. 11E), or row after row for a *grid* (P7). Interestingly, P20 used a needle and thread metaphor to weave through documents into the desired layouts.

Source-layout-oriented Transformation. Transformation can also be informed by the shape of the source layout. For instance, to achieve a better *overview*, a *vertical stack* was pushed down (P9, P11) or flicked over (P14) to form a *horizontal column* (see Fig. 9E), similar to pushing dominoes. Likewise, a *stack* was thrown onto the table, mimicking the action of tossing paper in daily life, to transform into a *grid* or *collage* layout (P8, P11).

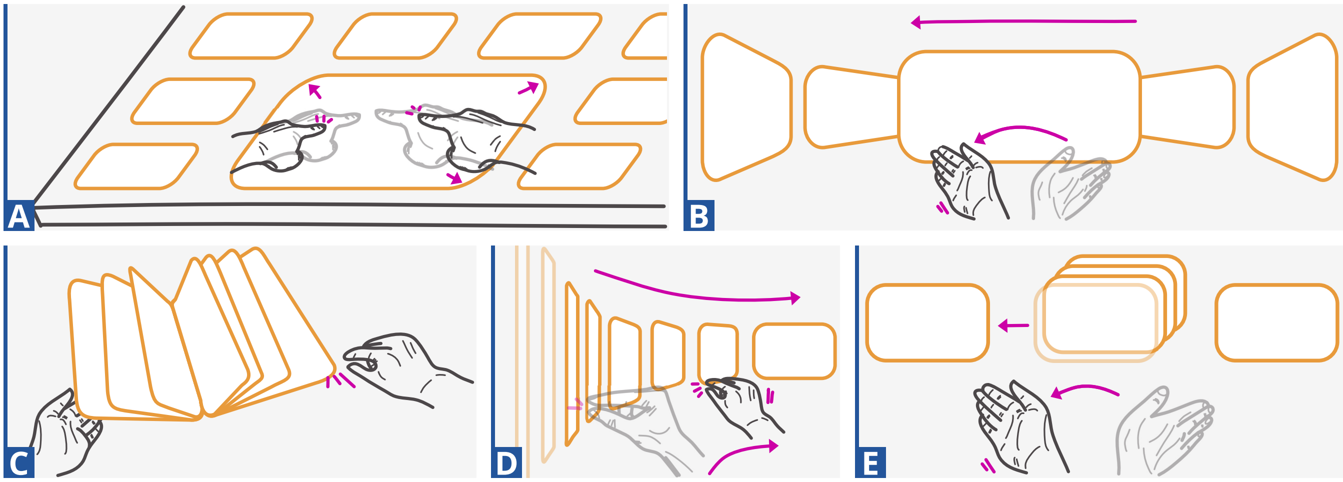

Figure 10: Five strategies for layout inspection and navigation, including (A) overview and detail as a grid on the table with a zoomed-in document, (B) swiping or scrolling a slideshow with focus and context, (C) turning pages to navigate documents, (D) scrolling a circular strip layout, (E) directional swiping for a rapid inspection.

4.2.5 Layout Inspection and Navigation. To obtain an overview and extract information, an **(1) overview and detail** strategy was used to inspect all documents in a group, such as a zoomable *grid* (P2, see Fig. 10A and Fig. 11I), an expandable 3D *node-link diagram* (P19), or a *sphere* layout centering the user (3/21). **(2) Slideshow** included layouts like *circular stripe* (3/21), *infinite straight stripe* (P15), and *grid* (P10). A focus and context approach can be joined to enlarge one document while others become distorted or overlapped (P14, see Fig. 10B). Several navigating techniques were combined, such as auto-play (P10, P20), scrolling by grabbing (4/21, see Fig. 10D), or swiping (P14). **(3) Metaphorically flipping** through a book-like *stack* (6/21, see Fig. 10C) was observed. **(4) Directional swiping** was used to move individual documents aside in succession to navigate through a *stack* for tasks like *searching* or *sorting* (see Fig. 10E and Fig. 11J). This created subgroups (3/21), roughly sorted for a better overview (P9, P14), cleaned up irrelevant documents for searching (3/21), or performed custom functions based on the direction (P15).

4.2.6 Reflection and Discussion. We identified various interaction methods (see Appendix Fig. A1) for workspace transition, document group management, and layout transformation and exploration. Most proposed interactions fit reality-based interaction [53], using actions resembling daily physical practices to interact with digital content. Many interactions were context-specific, mimicking office paper handling, while some were more generic, drawing from everyday experiences, such as *storing* in pockets or *separating* via scissor gestures. Unique metaphors like thread and needle, Spider-man superpower, and fishing rod were noted for direct and remote interactions.

The extent of interactions often matched the layout scope, e.g., gesture traversal distances corresponded to target layout scopes. Besides, participants used gestures of varying magnitudes, including one-thumb fanning, two-finger pinching, full-hand grasping, or even entire arms to manage different quantities of documents in the source layouts. There were also different control levels, from precise to rough, when interacting with documents. Groups could be moved individually to specific locations, rapidly swiped in any direction for *splitting*, or thrown toward a target for *translating*. Similarly, layout transformation can be achieved by brushing exact layouts or drawing symbols of shapes.

4.3 Participant Comments and Feedback

To reveal participants' attitudes and rationales, we summarize the results of the post-study interviews on general impressions, MR opportunities and trade-offs, and future use cases.

4.3.1 General Impression and User Experience. Participants appreciated the flexibility of AR devices (4/21), with visually appealing outputs (P8, P10) and diverse data representations (P3, P15). Most felt positive about using AR for document organization and believed in its future (18/21). They found it intuitive (P1-2, P8, P14) and easy to learn (P1, P14) due to direct interaction with content (P1). This intuitiveness contributes to a *"fun working style"* (4/21) instead of *"the tediousness of selecting and opening documents one by one [on desktop]"* (P9). Organizing documents in AR felt more controlled (4/21) as it is convenient to pack and rearrange documents (P7, P21) or *"[pull] documents in front of you in a bigger size"* (P17). Participants noted it as time-saving (7/21) due to ease of arrangement (P5, P17, P21) and the extensive space for content overview (P1, P17).

However, concerns were raised about hardware limitations like display resolution (3/21), limited field of view (P11, P16) influencing the text readability, or eye strain (P6, P10) and device weight (P11, P16) impacting long-term usability. Some also preferred physical paper (P11-12) or worried about adding another device to their workflow (P1).

4.3.2 Current Challenges and Opportunities. Current challenges in document arrangement included the effort required (P6-7, P11, P14). Participants noted AR's suitability for *"putting things in order"* (P14), structuring and arranging thoughts, and expressing and

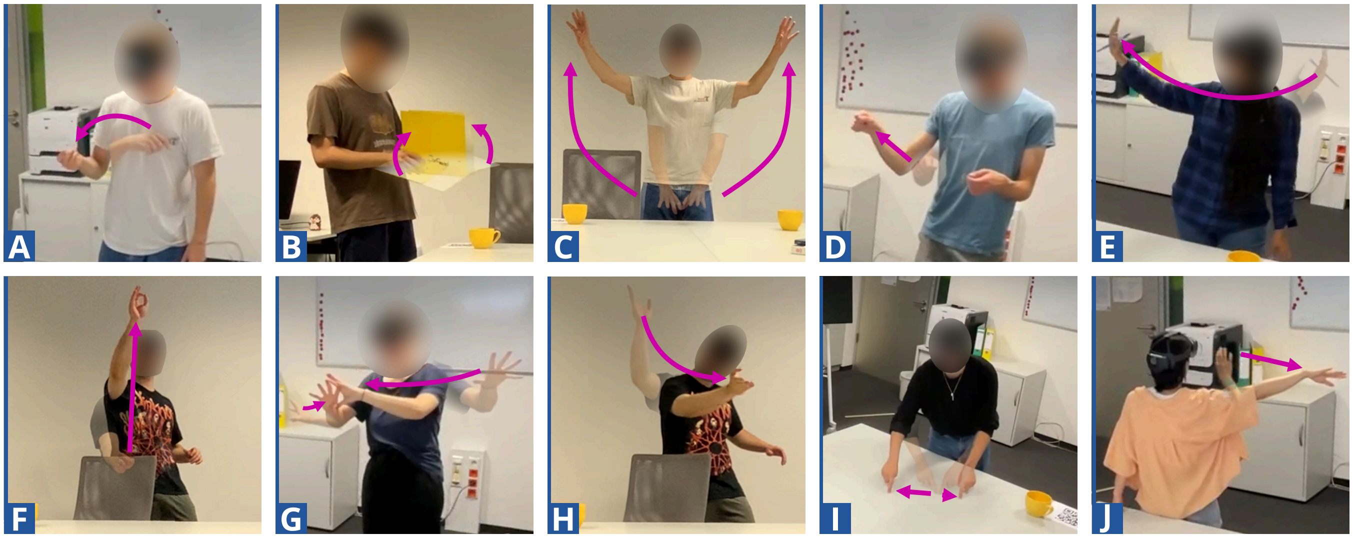

Figure 11: Examples of proposed interactions by participants: (A) P15 pulled out a group from his breast pocket. (B) P10 collected documents using a real folder. (C) P15 transformed a stack into a grid with a spread gesture. (D) P18 created a row with an accordion gesture. (E) P7 brushed a semi-circular layout. (F) P12 pulled a stack up to form a column. (G) P1 merged two groups by crashing them together. (H) P12 sliced a column to split it into two parts. (I) P2 enlarged a document from a grid on the table by zooming in. (J) P11 swiped through a stack to search.

representing them spatially (P9, P20). Interestingly, AR encourages more organization strategies since *"magnets and other tools are effort-taking, same as the desktop, while gesture [interaction] is more inviting"* (P21). The content messiness in AR was relatively acceptable (P21) and reversible (P14-15), enabling trial-and-error strategies.

Moreover, limited display space in current desktop systems can lead to a loss of overview (8/21). In contrast, in AR *"the whole environment is screen space"* (P16) for content placement (9/21). This enables to inspect documents at once (10/21), enhances content awareness (P2, P21), and improves the visibility of individual documents (P17).

Participants preferred placing content in *"[connection] to the real-world [environment]"* (P15), being *"impressed [how] the digital content [feels as] a part of the room"* (P18). They utilized walls and whiteboards (4/21), horizontal surfaces like tables (2/21), or both surfaces (3/21). AR can extend existing knowledge and workflow, as *"we act on the physical objects"* (P19), enhancing memorizing and relocating documents (i.e., *"as landmarks"*, P10). Lastly, essential documents following the user's body were recommended (P6).

4.3.3 Tradeoffs of Embodiment. Compared to desktop systems, AR documents offer a higher degree of embodiment, enhancing document organization, exploration, and comparison. However, this embodiment has limitations; distributing documents across expansive spaces can be overwhelming (P9) or discomforting during deep reading activities (P8).

Mid-air gestures are intuitive but have tradeoffs, as *"some low-level actions might require a bit more procedures"* (P9). For instance, *"for quick notes, AR can be too much overhead"* (P9) while *"physical paper allows for rapid and direct changes"* (P13). Hand gestures were also seen as less accurate *"considering the nuances of movement"* (P16), and participants expressed concerns about gesture recall (P13). In contrast, mice and keyboards were perceived as more accurate, easy to control due to familiarity (P16), and ergonomically friendly (P8).

4.3.4 Envisioned Use Cases. Participants envisioned AR for presentations (7/21), highlighting its mobility (3/21) and ability to deliver comprehensive content while reducing preparation barriers (P1), so *"no need to take all [organized] cards from the whiteboard, go to my neighbor's office, and then put them all again"* (P13). Audiences could also actively engage with content on demand based on personal interests (P9), *"making it easier to understand each other"* (P21).

Participants also suggested co-located (5/21) or remote and mixed presence (4/21) collaboration scenarios. A shared space allows *"everyone [to] make changes"* (P14) with situational awareness, making it *"easier to see everything and what everybody is doing"* (P2) and aiding in shared categorization strategies (P21). The presence of the real-world environment also allows collaborators to freely *"paste and drop [documents for someone else] anywhere using the environment"* (P5).

4.4 From Study to Design

Our formative study explores interaction techniques and provides a comprehensive understanding of virtual document organization activity. Based on these findings, we aim to inform the design of future MR systems. We focus on 2D documents, prevalent in both virtual and physical environments and well-suited for information abstraction use cases (e.g., texts, posters, floor plans). We present a design space (in Sec. 5) that outlines essential components and properties of AR systems for content organization. We distill design implications (see Sec. 6) using the vocabulary from the design space to consolidate its knowledge and guide system design. Finally, we demonstrate practical scenarios (see Sec. 7) that leverage the design space and design implications.

5 Design Space

Our design space consists of four components: Workspace, Layout, Task, and Interaction (see Fig. 12). To spatially organize AR documents for a specific task (**why**), users interact with (**how**) documents and their layouts (**what**) situated in a particular position (**where**).

Where - Workspace. It describes a user-defined space **where** documents are situated and interacted with. The workspace consists of physical environments, like tables or the users themselves, as well as virtual documents. Informed by prior research on egocentric and exocentric frames of reference [30, 65, 76], we describe the following dimensions:

Reference/Anchor: Connection to a point or object in an immersive environment.
- **User** of the immersive system.
- **Object** in the situated environment, like a book.
- **Environment**, including architectural elements such as the ceiling or walls.
- **Open Space** without an anchor.

Proximity: Distance between documents and their reference.
- **On/In** the reference, directly placed or aligned to.
- **Near** to the reference, like in arm's reach of the user.
- **Far** away from the reference.

Anchor Coupling: How documents behave when their reference moves.
- **Persistent**, as documents follow when the reference moves.
- **Temporary**, as documents remain static when the reference moves.

Visibility: Whether documents are visible to the user.

What - Layout. A layout is a visual representation of the spatial organization of **items** within a **group**, which is **what** users are working with. Each **item** can either be a group or a document, and each **group** is associated with a specific **layout**. We clarify its attributes (see Fig. 13):

Number: The count of documents contained in a layout.
Shape: The geometry of a layout such as stack, column, row, grid, and fan.
Orientation: Alignment to the anchor (or to the ground if anchored to *Open Space*), like parallel or orthogonal.
Dimension: Distribution of documents in 1D (i.e., line), 2D (i.e., plane), or 3D (e.g., cube) space.
Curvature: The shape's curvature, like flat (0°), semi-circular (180°), or fully-circular (360°).
Strictness: Alignment among documents according to a specific pattern, ranging from unordered to ordered.
Compactness: Average distances among the documents, from sparse to compact.

Why - Task. Users organize documents to achieve specific goals. We identify the following tasks to indicate **why** users organize. The first three dimensions are elemental, supporting the achievement

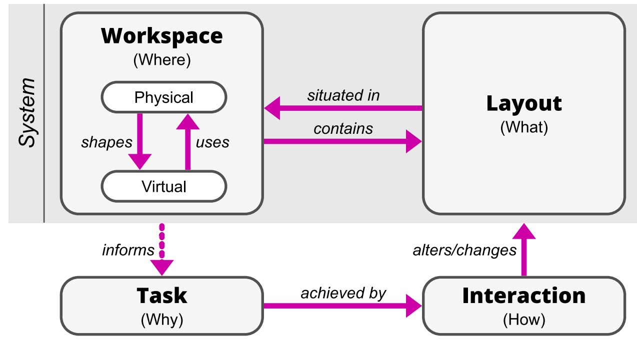

Figure 12: Design space for AR document organization, consisting of four key components: Workspace, Layout, Task, and Interaction. Arrows indicate the relationships between these components.

of high-level goals [69], and can also become primary goals in their own right.

Item Clustering: Organize items and their relations within layouts.
- **Group/Ungroup** to combine/dissolve items as/from a group.
- **Add/Remove** items to/from a group.
- **Merge/Split** to combine two groups into a new one or divide one into multiple.

Layout Arrangement: Structure the layout of items.
- **Spread/Compress** to increase/reduce the layout's compactness.
- **Transform** to modify the layout's attributes.

Workspace Management: Organize items in an MR environment.
- **Translate** to alter the position of items within a workspace.
- **Transit** to move items to another workspace.

Visual Exploration: Extract and compare information from items visually.
- **Preview** to create a quick overview of content within a group.
- **Inspect** to build an understanding of items and their relations within a group.
- **Search** to seek an item or other specific information.
- **Sort** to order items within a group according to specific criteria.

Annotation: Add additional information to items, groups, or workspaces, such as notes or glyphs.

How - Interaction. Interaction defines **how** users manipulate documents into a specific layout for particular tasks.

Modality: Input methods, like freehand, gaze, body movements/gestures, or speech.
Style: Relation of the interaction to the real world (i.e., realistic, metaphoric, or abstract).
Body Involvement: Extent of physical engagement, like only flipping the wrist vs. moving the whole arm.
Motion: Nature of the performed interaction.
- **Speed** of the interaction (i.e., fast to slow).
- **Precision** of the interaction (i.e., high to low).

6 Design Implications

Based on the study results, we distill design implications (**I1-7**), applying the vocabulary provided in the design space.

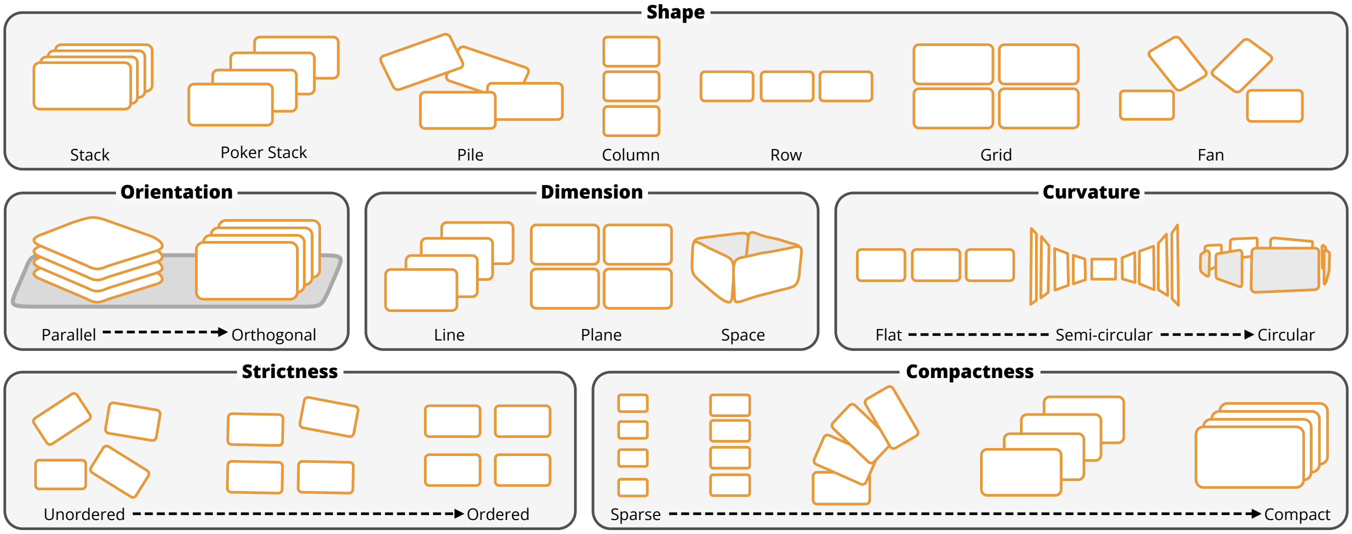

Figure 13: Layout component of the design space, highlighting the geometric attributes of a spatial layout. This component includes quantitative attributes such as *Number* (not shown in the diagram), *Orientation*, and *Curvature*, the categorical attribute *Shape*, and ordinal attributes including *Dimension*, *Strictness*, and *Compactness*.

I1 - *Anchor documents to users' bodies to aid the arrangement process.* MR HMDs allow users to arrange content in the surrounding space, enabling unrestricted movement without confinement to a fixed position. Anchoring documents on the user's body provides convenient quick-access storage. The near-body space can serve as an effective workbench, offering both visibility and direct interaction with individual documents, as well as an overview of document collections.

I2 - *Support spreading and compressing for workspace transition and layout transformation.* Spreading and compressing adjust the compactness of layouts. Compact layouts help reduce visual clutter and facilitate batch operation, such as transformation, translation, and workspace transition. In contrast, sparse layouts enhance the overview and accessibility of the individual documents. As observed in the user study, alternating between compact and sparse layouts is essential for the arrangement activities.

I3 - *Design hand gesture interaction based on the source layouts to transform.* The shape, orientation, distribution, and compactness of layouts inform how they can be transformed. These affordances are rooted in everyday experiences and common understandings of physics (also see **I7**). For instance, when spreading a document stack, one can fan out, push down, pull up, chain out, or throw to expand on surfaces.

I4 - *Use hand gestures and their motion to define the desired layouts.* Hand gestures are intuitive and powerful for expressing spatial information needed to define layout attributes. The movement of hands and the paths they trace can indicate the boundaries and occupied space of desired layouts (i.e., drawing a frame). Gestures can also specify the exact shape, orientation, distribution, curvature, and compactness of layouts (i.e., brushing).

I5 - *Align body involvement with the number and compactness of layouts.* The number and compactness of document layouts suggest the expected effort to manipulate them. Therefore, interactions used to arrange these documents can correspond to this effort through the level of body involvement. This allows for appropriate referencing of documents, such as using fingers for single items, whole hands for groups, or both arms for several groups.

I6 - *Prioritize hand-based interaction and supplement with other modalities as needed.* Hand gestures are central to virtual document arrangement. However, we also propose integrating additional modalities to enhance the document organization process. For instance, voice commands can be used to locate known targets or move documents to predefined locations (like the "put-that-there" approach [12]), while gaze can serve as an implicit input alternative.

I7 - *Leverage interaction rooted in physics and real surroundings.* Adopting realistic interaction styles allows users to apply their knowledge of physics and real surroundings to the digital realm. Physical entities like surfaces and objects can serve as tangible proxies or tokens to store or translate documents, supporting arranging activities. However, we also encourage exploring "out-of-context" metaphors, such as threads and needles, fishing rods, and Spider-man superpowers.

7 Design Demonstration

We demonstrate our design space and implications for future MR document management systems. We first introduce a keyframe-based rapid prototyping system designed to facilitate the interaction design (Sec. 7.1). We also illustrate three envisioned use cases (Sec. 7.2). Source code and a step-by-step tutorial are available on our project website[3].

[3]https://imld.de/AR-Docs

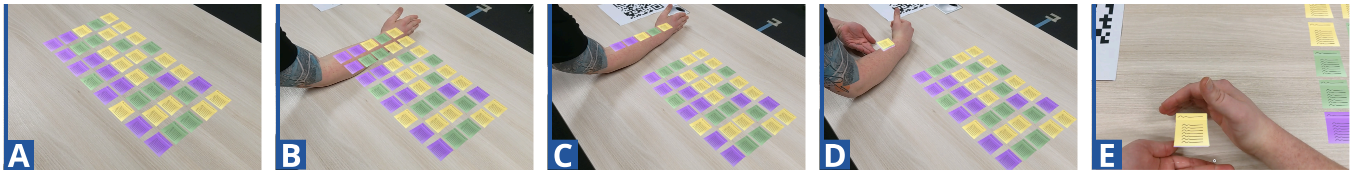

Figure 14: To cluster sticky notes: (A–C) splitting off the left column from the grid; (D+E) compressing the column into a stack.

7.1 Rapid Prototyping System

Facilitating the design of interaction techniques for immersive environments has gained attention [6, 59]. It presents greater challenges compared to traditional setups due to the vast range of interaction possibilities and the limited means of experiencing and communicating these options within a design team before a fully functional system is developed. Animations can be a cost-efficient solution to allow direct engagement with prototypes, compare design alternatives, and evoke first-hand insights [45]. We thus introduce a rapid prototyping system that creates interaction mock-ups with keyframe animations, using a Wizard-of-Oz approach [56, 86] by externally triggering these animations.

We developed a Unity package with MRTK[4]. Designers can test interaction designs with animations on MRTK-compatible devices, such as HoloLens 2. An animation blueprint (prefab) can be imported by drag-and-drop, containing keyframes for start, end, and in-between states. Users can define where virtual objects start, traverse, and stop in the Unity scene, and anchor objects to points like the non-dominant hand. Users can also customize state transitions, including triggers (e.g., automatic or key-pressing), duration, and format (e.g., acceleration/interpolation). The resulting animations can be viewed on MRTK-supported hardware. We integrated a network feature via photon[5] to capture interactions from multiple perspectives (first-/third-person views).

This system allows designers to conceptualize, test, experience, communicate, and iterate on interaction techniques informed by our design space. Designers can act out interaction variants and assess their suitability with HMDs, capturing interaction techniques as video from various perspectives for discussion. We illustrate several prototyped interactions with three envisioned scenarios in the following (also see the video figure).

7.2 Envisioned Use Cases

We illustrate three use cases to demonstrate the richness of our design space, the practicality of design implications, and how MR can empower the daily activities of knowledge workers in text analysis, task management, and design iteration. Guided by our design space and implications, we highlight **why** documents are being arranged (*task*), **where** they are arranged (*workspace*), **what** kind of *layouts* they are in, and **how** they are being arranged (*interaction*).

Sensemaking with Affinity Diagramming. Alice, a psychologist, uses an MR affinity diagramming tool to analyze user study quotes and communicate findings (see Fig. 14). She stands in front of a wall-mounted whiteboard with a *table* on her right, where forty participants' comments are imported as sticky notes in a *grid*.

To get a general impression of each participant's comments, Alice *splits* off statements with her right arm, sliding the first column away (*I5*; see Fig. 14A-C). She *compresses* this *column* into a *stack* with her right hand and collects it on her *left hand* (*I3* & *I4*; see Fig. 14D+E). She *inspects* this group in detail via a book-flipping gesture (*I7*), then places it back on the table, repeating the process for other participants.

To *sort* the statements, Alice *pulls up* a *stack* like a chain into a *column* (*I3*, *I4* & *I7*), *pinches* the suitable item, and *throws* it (*I7*) to the *whiteboard*, creating six groups in a *grid*. Noticing similarities between the two groups, she *merges* them by *pointing at* both with open-flat hands (*I5*), *forming fists* to draw the groups closer, *crashing* them together into one group, and *throwing* it back to *the whiteboard* (*I7*), resulting in the final thematic map.

For an alternative overview-focused *inspection*, Alice can *spread* (*I2*) the stack into a *slideshow* layout using an accordion gesture (*I4* & *I7*), instead of a book-flipping approach. This allows her to *swipe* and *inspect* document groups with the context from previous and following notes.

Office Task Management. Bob, an administrative secretary, uses his MR system to *sort* emails by importance and topic (see Fig. 15). Emails are displayed as a *horizontal stack* floating *in front of and following* him (*I1*), with newer items positioned closer. Using *directional swiping gestures* (*I3* & *I4*), he moves emails up, down, left, and right, resulting in four groups as *piles*: high-priority, low-priority, postponing, and decision-required.

Bob *assigns* sorted documents to physical objects in his office (*I7*). High-priority and decision-required groups are placed in two *stacks on his table* for immediate attention. The postponing group is placed inside the *folder cabinet*, *spreading* as a *column* when viewed (*I6*). The low-priority group is *thrown* to the *cupboard* behind him (*I7*).

Bob then *inspects* high-priority and decision-required groups in a *slideshow* layout. Emails requiring colleagues' inputs are *selected* into a *stack* and *stored* in his *pocket*, becoming invisible. Bob walks to his colleagues' office, *pulls out* the *stack*, and attaches it to the *door* with a thumb-tack gesture (*I7*).

Alternatively, if Bob meets his colleague in the corridor, he can pull and *fan out* the stack (*I2*) on *his hand* (see Fig. 15A+B), *fetch* the email with one finger (*I5*), and *enlarge* it in *open space* for an ad-hoc discussion (see Fig. 15C-E).

Graphic Design Iteration. Lizzy, a graphic designer, uses an MR system to iterate on her paper poster with AI-generated variants

[4] https://github.com/microsoft/MixedRealityToolkit-Unity
[5] https://www.photonengine.com/

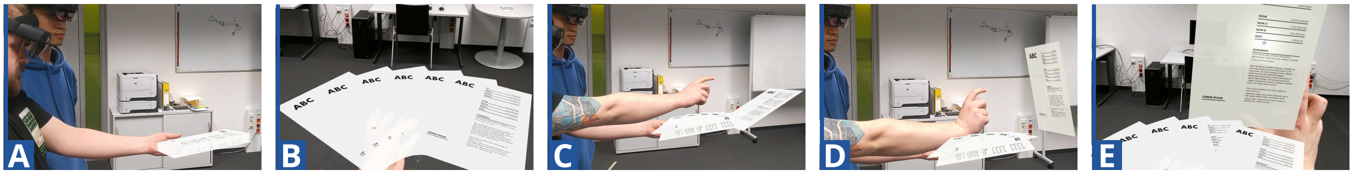

Figure 15: To manage documents: (A+B) fanning a stack out; (C-E) selecting and enlarging a single document from the stack.

Figure 16: To compare graphic design variations: (A-C) transforming a stack into a row by brushing the resulting layout; (D) tapping to snap selected files onto the fingertip; (E) drawing to arrange a grid layout around the physical poster.

(see Fig. 16). She imports these posters, arranging them on her *desk* as seven *piles* based on similarities.

To *sort* them, she *fetches* a *pile* and *draws a line* (*I4*) in the air from right to left with her open hand (*I5*, see Fig. 16A-C). The items are then spread (*I2*) along this movement as a *row in front of her* (*I1*). She *drags* her favorite designs to the left (*I5*), resulting in a *row* ranked by preference. The group is then *compressed* (*I2*) into a *stack* and placed *on the table*, with the favorite item on the top for *previewing*. Finally, she *pulls and pushes* selected virtual posters *next to the original paper poster* on the wall, enlarging to the printing size for direct comparison.

Alternatively, Lizzy can compare the best items simultaneously by grouping them with her finger by tapping them (*I5*, see Fig. 16D) and then drawing a rectangle around the paper poster on the wall (*I4*). This arranges the group as thumbnails *around the poster* (*I7*), allowing for a side-by-side comparison (see Fig. 16E).

8 Discussion of Limitations and Future Work

We discuss current limitations, relate our findings to prior work, and outline directions for future research.

Document Content and Relation. Our study employed documents containing multi-dimensional information (i.e., texts and images) that represent common document types [81, 125]. This generalization allows us to focus on how users utilize space based on tasks and articulate such usages via interaction, independent of specific content. Consequently, we derive a flexible design space applicable to various documents. Our findings are particularly relevant for managing sets of homogeneous documents, a use case increasingly prevalent in 3D environments. Examples include text documents (e.g., reports [21], survey responses [74]), graphics (e.g., medical imaging [10], maps [109]), and data visualizations (e.g., spreadsheets [39, 52], charts [76]). Our findings can also be applied to documents with diverse semantic relations. Sequential relations (like storybooks [25]) can be authored using brushing gestures, where the start position defines the first page. Hierarchical relations can be supported with nested layouts or arrangements where the primary content is anchored by multiple secondary documents (e.g., [62, 108]). However, further investigation is necessary to understand how inter-document relations and content uniformity, particularly considering various shapes, sizes, and content of individual documents and their combinations, might affect layout and interaction.

Workspace Characterization and Partition. Prior work has discussed body-centric proximal spaces (i.e., personal, peripersonal, and extrapersonal space) [18, 112] and the proxemic ecology [41] in multi-device environments, as well as space perception [76], and reference dynamicity [96] in immersive environments. In the context of AR document management, while our classifications of body-centric (on-body and arm-reach) space align with these works, we further highlight physical-environmental and open spaces. We also elaborate on potential usage preferences: on-body space for storage, arm-reach space for manipulation, open space for final arrangements, and environmental space for both manipulation and presentation. This aligns with using peripersonal (arm-reach) space for interaction in immersive environments [30, 76, 131], but contrasts with active on-body interactions suggested in multi-device environments [120]. Future work should place greater emphasis on real environments for content organization (e.g., landmarks [79, 81] and tangibility [130]) and on supporting transitions between workspaces (e.g., perspectives [67] and gestures [96]).

Multi-Document Arrangement. Our findings demonstrate the potential of direct interactions, such as drawing layout shapes and frames, to arrange multiple documents, highlighting the expressiveness of hand gestures. While some similar techniques have been explored with interactive tabletops [1, 36, 128], we extend this understanding to document arrangement in MR environments, where increased space enables new strategies, such as directional swiping gestures. We also observed participants leveraging physical environments and objects as natural alignment aids, including landmark objects, furniture edges, vertical and horizontal surfaces, and distinct workspaces. This is similar to prior work employing shape constraints and guides, such as points [46, 126], lines [36, 126], canvases [68, 95], and grids [7, 35, 111] in 2D and 3D contexts. We encourage further exploration of actively integrating physical surroundings into arrangement tasks. Future work can also examine how different approaches—such as direct hand drawing as well as virtual and physical aids, used individually or in combination—can enhance the organization of multiple documents.

Evaluation of Design and Usability. We adopted a broad user-centered approach to explore the design space of interaction techniques for MR systems, enabling us to identify characteristics, associations, and tendencies related to workspace, layout, tasks, and interactions. However, this methodology may be limited by current hardware (e.g., restricted field of view), participant backgrounds (e.g., demographics and technological literacy), and legacy bias (e.g., priming from paper documents). Additionally, this methodology aims to maximize participant creativity, it however does not necessarily consider implementation details of real-world systems [70]. Further investigation is needed into interaction detection and conflicts among interactions [114, 119]. Participants in the interview were mainly concerned about eye strain and hardware weight for long-term use rather than fatigue from hand gestures. However, challenges like the "gorilla arm" effect caused by mid-air interaction [33, 49] can arise. To mitigate this, mid-arm gestures can be supported [44], constrained [105], or combined with micro-gestures [17] or with other modalities such as gaze [17, 64] and foot [76, 122] inputs, as also suggested by our results. While our rapid-prototyping system provides a starting point for evaluating interaction techniques, a thorough evaluation would require narrowing to specific documents and tasks. Future research can apply our design space to concrete applications, verify design implications within specific contexts, and examine metrics such as ease-of-performance, learnability, memorability, and reliability of interaction.

Future MR-enabled Office. Our study focused on participants in a standing posture, as we anticipate that knowledge workers will move within future offices. Such mobility could enhance space utilization, stimulate cognition through physical movement, and promote a healthier work style. However, considering fatigue associated with prolonged use, it is necessary to explore designs that support seated usage as alternatives and facilitate transitions between different user postures. Moreover, integrating other existing devices like desktop computers and their peripheries to leverage combined strengths is of interest, as demonstrated in research on complementary [51, 134] and transitional interfaces [88]. Specifically, further investigation is needed on how documents and layouts can be consistently transferred across different workspaces or interface types. Finally, extending our findings to multi-user scenarios, like collaborative brainstorming and sensemaking [81, 132], and designing interactions for shared and individual workspaces [47, 55] would be a promising direction.

9 Conclusion

We investigated the spatial arrangement of virtual documents in Augmented Reality. To this end, we conducted a user-centered design study, eliciting interaction techniques in an office environment. We systematically analyzed and reported both quantitative and qualitative results. To support system design, we proposed a design space, summarized design implications, developed a rapid prototyping system, and demonstrated three envisioned use cases. Our goal is to enable designers and developers to create immersive applications that leverage realism and spatiality, empowering knowledge workers to manage documents and information intuitively. Ultimately, we aim to inspire further exploration of spatiality in immersive environments and inform the design of future mixed-reality-enabled offices.

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A Appendix

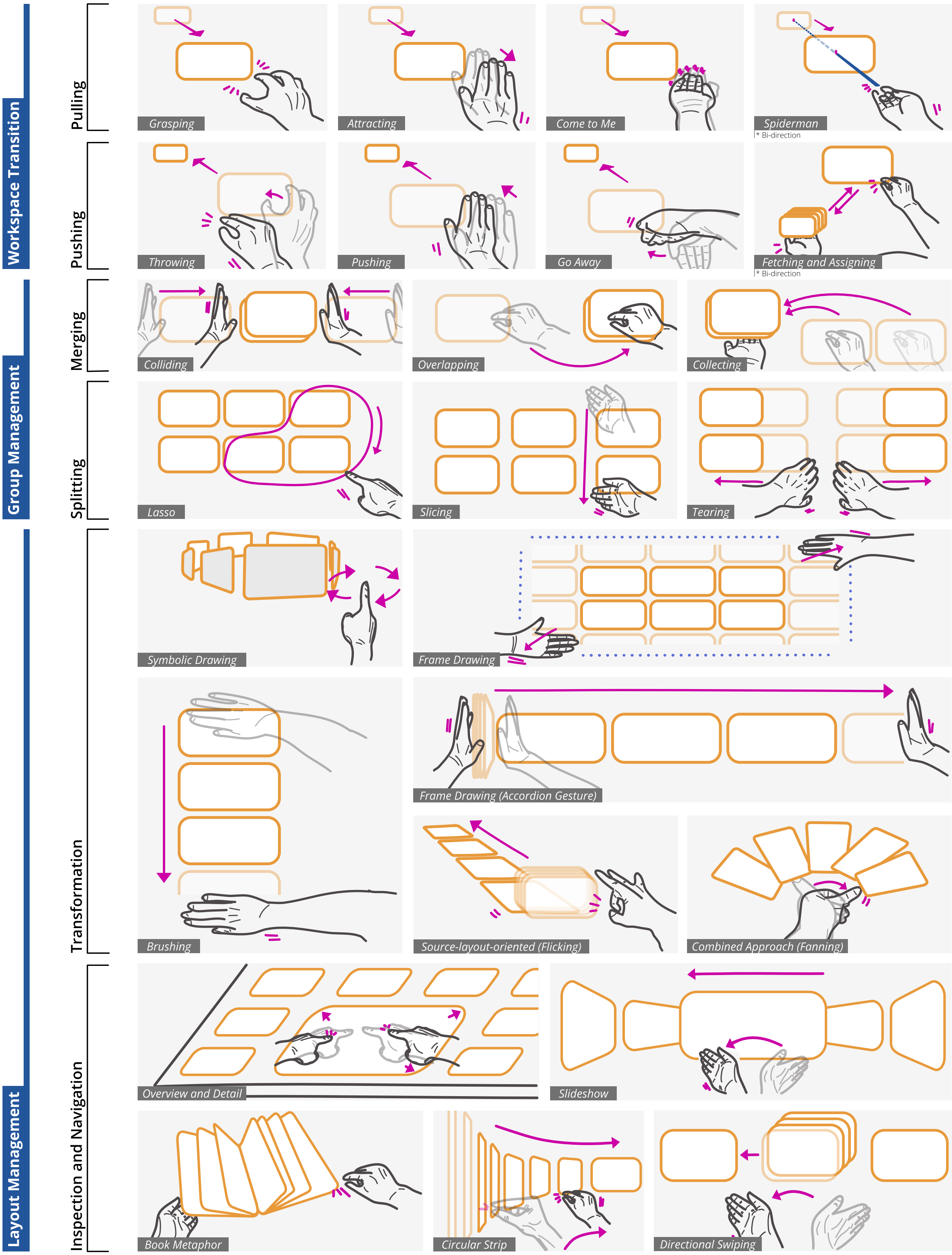

Figure A1: Overview of the major observed interactions in this paper.