Exploring Spatial Organization Strategies for Virtual Content in Mixed Reality Environments

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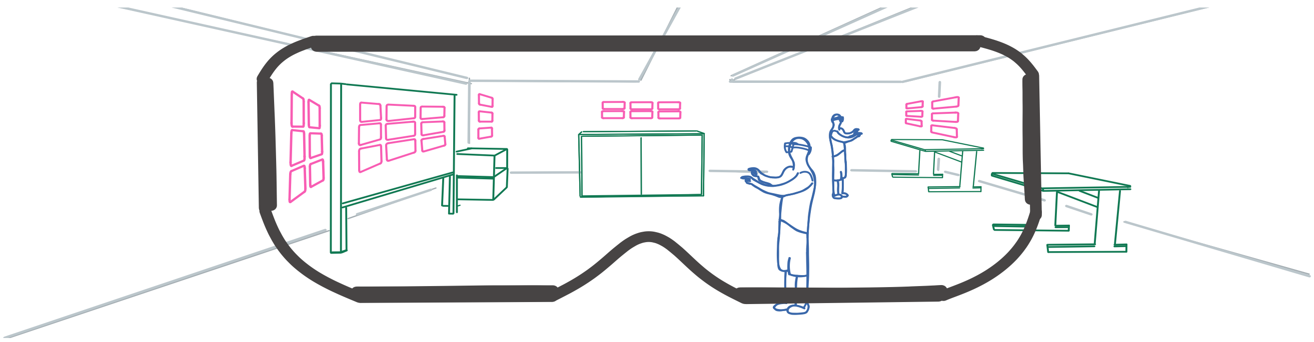

Figure 1: A scenario of organizing mixed-reality content spatially. When arranging virtual content (in pink), users who wear mixed reality headsets are often influenced by their real-world surroundings. Such surroundings consist of 1) physical environments like furniture and architectural elements (in green) and 2) people present (in blue).

ABSTRACT

Our future will likely be reshaped by Mixed Reality (MR) offering boundless display space while preserving the context of real-world surroundings. However, to fully leverage the spatial capabilities of MR technology, a better understanding of how and where to place virtual content like documents is required, particularly considering the situated context. I aim to explore spatial organization strategies for virtual content in MR environments. For that, we conducted empirical studies investigating users' strategies for document layout and placement and examined two real-world factors: physical environments and people present. With this knowledge, we proposed a mixed-reality approach for the in-situ exploration and analysis of human movement data utilizing physical objects in the original space as referents. My next steps include exploring arrangement strategies, designing techniques empowering spatial organization, and extending understandings for multi-user scenarios. My dissertation will enrich the immersive interface repertoire and contribute to the design of future MR systems.

CCS CONCEPTS

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

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KEYWORDS

Spatiality, spatial layout, content organization, affordance, Augmented Reality, Mixed Reality

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1 INTRODUCTION & BACKGROUND

Immersive technologies like Mixed Reality (MR) Head-Mounted Displays (HMDs) have the potential to revolutionize our lives. Places like offices will likely be equipped and enhanced by MR HMDs in the future to enrich the current working environment with virtual content. Documents like text, images, spreadsheets, and presentation slides will no longer be confined by rectangle monitors. Instead, holographic counterparts can be placed anywhere in the future office environment, fully leveraging the infinite display space. In fact, various activities have been explored for immersive offices, such as working with general documents [17, 29], exploring brainstorming notes [5, 32], creating design sketches [13, 42], and analyzing data diagrams [15, 19, 20]. Compared to Virtual Reality (VR) that isolates users from reality, MR is more suitable for these everyday office activities, as it maintains the context of real-world surroundings. This supports collective activities with shared awareness [23], allows for easier adoption and integration into the existing workflow [44], and enables the extension and adaption to changeable circumstances [29, 33]. Altogether, these highlight the great potential of MR technology in the workspace.

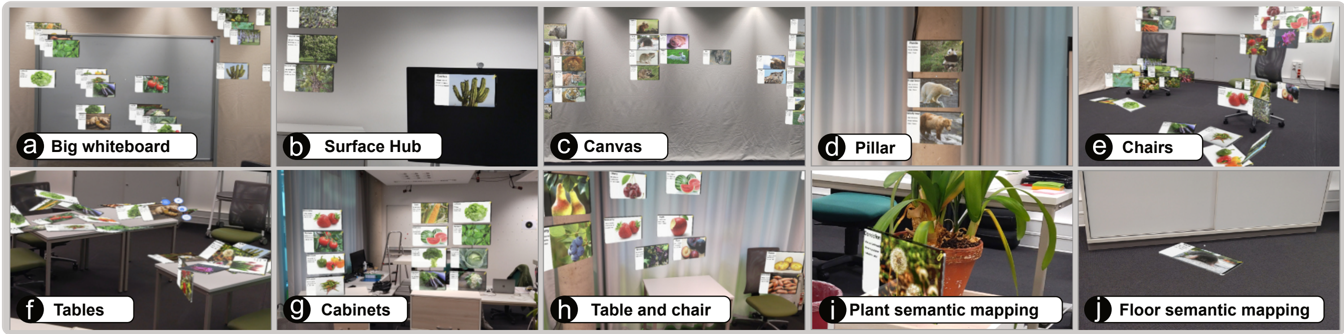

Figure 2: Participants placed MR documents anchoring to furniture and architectural elements for sensemaking in our work [23], including vertical surfaces (a, b, c), horizontal surfaces (f, g, h), the pillar (d), chairs (e), and placement with semantic mapping (i, j).

However, there is a lack of understanding regarding content placement options for future MR interfaces, particularly in the context of real-world surroundings and the spatiality enabled by the output capability. From physical paper [26, 46] to digital files on traditional desktops [1, 3], prior works have proven that users tend to use position and space as means to structure and organize information. For immersive technology, previous works like content organization [15, 18, 39], window layouts [8, 11, 35], and view management [19, 20] in the context of Immersive Analytics (IA) [27] have shown that the data analysis process can benefit from an appropriate design of the content layout. Moreover, several form factors of content layout and placement have been discussed, including the number of visualizations [20], the user task [21, 39], and the dimensionality of the visualizations [15]. Nevertheless, they either only focused on VR environments or lacked considerations of real-world context, which is the inherent nature of MR. Particularly, the effect of physical environments on MR content layout and placement is still unclear. Affordances of objects like furniture, considering its geometry and semantics, have not been sufficiently discussed. Moreover, although activities like brainstorming, sensemaking, and presentation are intrinsically multi-user, adapting layout and placement to the involvement of people present has seldom been examined.

Related works have suggested integrating and contextualizing holographic content (e.g., data visualizations [16, 47]) into reality by placing it near or embedded in physical objects. Furthermore, locations like physical surfaces can be the anchors for content placement [31], such as aligning to ceiling and floor [37] or other 2D displays [14, 22, 34]. Moreover, generic heuristics have been considered to support placement decisions in the real world, including visual salience, spatial consistency [10], and real-world backgrounds [36]. Aside from this, the semantic association between virtual content and physical environments has also been considered for photo presentation [2] and general interface layout adaptation [4] in MR. For a working scenario, Spatial Analytic Interface [9] advocated that users should work in situ where information is semantically associated. Recent works further explored this topic concerning how to present and arrange content (like charts) in relation to its physical referent [16, 40] as well as the pros and cons of different coordinating layouts [38, 45]. In addition to physical objects, related work (e.g., mirrored layout [13] or subjective views [41]) has also considered people present in the environment for view arrangements. Lastly, several techniques have been demonstrated to facilitate the arrangement process, such as automatic alignment [4, 31], semi-automated arrangement [30, 43], and optimal area detection [28]. These works highlight the necessity to consider the real-world surroundings and situated contexts for the spatial organization of MR content. Nevertheless, knowledge of presenting, placing, and arranging information in MR and corresponding design guidelines is still lacking [7].

2 OVERVIEW OF RESEARCH QUESTIONS

I aim to contribute a better understanding of content organization options and factors in designing future MR systems. To clarify, I describe the spatial organization of mixed-reality content as an activity using certain arrangement methods to achieve the layout and placement of multiple pieces of content in a given real-world surrounding (see Fig. 1).

With this, my dissertation explores the following research questions:

RQ1: How would users place and organize virtual content considering real-world surroundings? I first investigated how users organize virtual documents in a given real-world context. My aim was to comprehend how the presence of people and physical surroundings influence the placement and arrangement of content. This sets up an overarching foundation for my dissertation.

RQ2: How can designers utilize physical environments for organizing virtual content? Inspired by the results addressing RQ1, I explored the utilization of physical environments for organizing virtual content, particularly considering affordances suggested by geometry and semantic characteristics of environments.

RQ3: How would users arrange virtual content for the organization tasks? With varying purposes, organizational activities like grouping and spreading can be dynamic and require user involvement in adjusting content placement and layout. We want to understand user practice and support this workflow with interaction techniques.

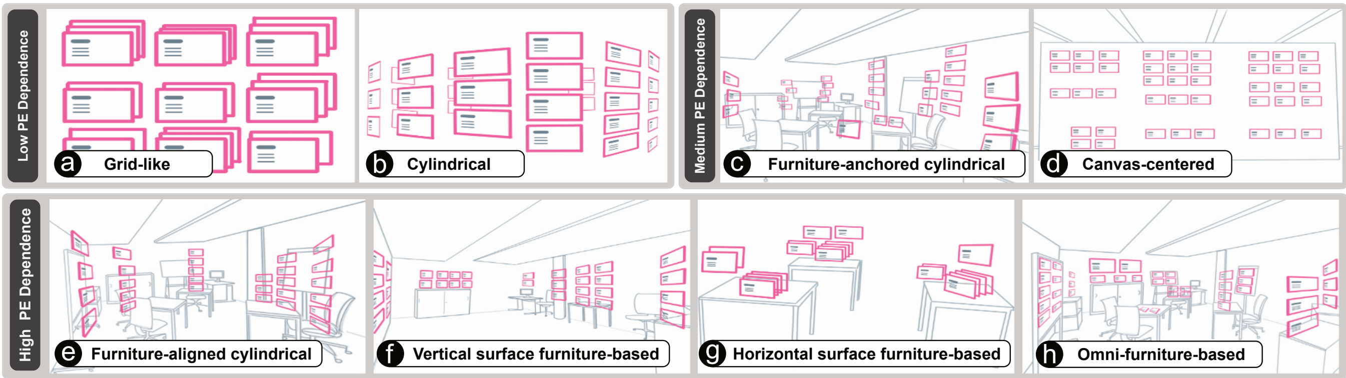

Figure 3: Participants achieved various layouts to organize MR documents spatially in our work [23]. We categorized these strategies based on the degree of dependence on the physical environment (PE) from low (a-b), medium (c-d), to high (e-h).

RQ4: How can virtual content be placed and organized considering the people present? Real-world surroundings consist of not only relatively static entities like physical objects, but also the presence of people. In particular, depending on the involvement in the ongoing activity, these people can be collaborators with similar goals, users with different roles, or even bystanders. Thus, we aim to investigate content organization considering the dynamicity of multiple users and their social context.

3 RESEARCH TO DATE

So far, several projects have been conducted, and results have been published in CHI '22 and '23. I applied a number of methodologies for these projects, including literature review, qualitative user studies like lab-controlled experiments and expert evaluations, visualization and interaction design, and prototype development. Specifically, we investigated virtual document placement and layout strategies and examined the real-world factors (RQ1) [6, 23, 24]. Furthermore, we presented PEARL [25], a mixed-reality approach for analyzing human movement in situ, exemplifying how designers and researchers can utilize the physical environments with MR content (RQ2).

Understanding Real-world Surroundings (RQ1). MR could likely benefit office activities, especially for collaborative brainstorming and sensemaking. However, it is unclear how physical environments and co-located collaboration influence the spatial organization of virtual content for sensemaking. For this, an initial user study (N=8) [24] and a full-extent user study (N=28) [23] were conducted. We investigated the effect of office environments (fully-furnished vs. partly-furnished) and work styles (individual vs. collaborative) during a document classification task using Augmented Reality (AR) with regard to content placement, layout strategies, and sensemaking workflows. Results showed that furniture like tables and whiteboards were required to assist content organization for sensemaking and collaboration regardless of room settings (see Fig. 2). Moreover, furniture usage was prioritized in the collaborative context despite personal layout preferences. We identified different layout strategies, from vertical and horizontal surface furniture-based layouts that highly depend on physical environments, to grid and cylindrical layouts that are little related to physical environments (see Fig. 3). Lastly, we proposed design implications to guide the design of MR applications.

Moreover, we further investigated how situated environments influence user perception of virtual content layout through another user study (N=8) [6]. Based on this, we theorized the relation between virtual content and its real-world context by introducing a two-dimensional design space (spatial and semantic coupling) with associated parameters (e.g., position and rotation).

Our works were the first attempts to reveal the organization strategies of virtual content with a focus on real-world surroundings. In particular, for organizing virtual content in MR, physical environments and people present are crucial aspects to be considered. Based on this foundation, I further develop my dissertation with the following research.

Utilizing Physical Environments (RQ2). To demonstrate the application of gained knowledge in RQ1, we introduced PEARL [25], a mixed-reality approach for the analysis of human movement data in situ. In indoor environments, human movement is often affected by physical objects populating a space and their affordances. A physical object might be an obstacle that has to be avoided to continue the movement or an object of interest that is intentionally approached to interact with it. Thus, physical environments restrict, shape, or elicit human behavior and motion. Hence, analyzing such motion can benefit from the direct inclusion of the environment in the analytical process.

PEARL contains methods for exploring movement data in relation to surrounding regions of interest, such as objects, furniture, and architectural elements. We introduced concepts for selecting and filtering data through direct interaction with the environment. Besides, a suite of visualizations (see Fig. 4) was designed to be associated with physical referents for revealing aggregated and emergent spatial and temporal relations. To illustrate its potential, an AR-based prototype was developed and reviewed via expert evaluations and scenario walkthroughs (N=4) in a simulated exhibition. We systematically analyzed the results and reported the first insights of our approach. PEARL lays a foundation for utilizing physical environments in the in-situ analysis of movement data.

This work is a demonstration of the design guidelines derived from RQ1. In particular, it illustrates how to position virtual content

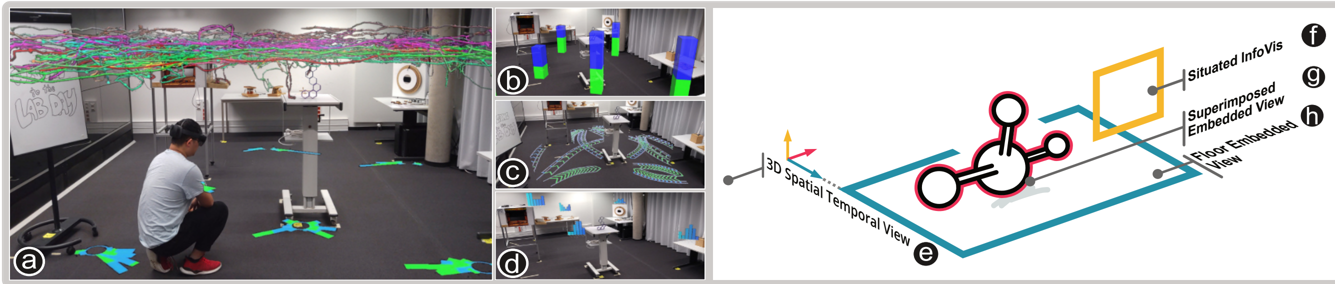

Figure 4: Our PEARL prototype with various MR visualizations anchoring to physical objects (a-d) for analyzing human movement and a placement scheme organizing four types of MR visualizations (e-h). 3D trajectories showing human movement are placed in the open space in (a) and (e); 3D bars superimpose on the associated physical objects in (b) and (g); movement flows are embedded on the floor in (c) and (h); 2D information visualization panels are placed side-by-side in (d) and (f).

in physical environments and the value of utilizing such environments for designing MR systems, thus answering RQ2.

4 NEXT STEPS

Next, I plan to explore arrangement strategies and interaction techniques for organizing virtual content (RQ3). Moreover, I aim to extend the understanding of real-world surroundings by focusing on the people present (RQ4).

Exploring Spatial Arrangement Strategies (RQ3). Participants in our studies [23, 24] appreciated the potential and benefits of being able to arrange virtual documents spatially, even with simple direct interaction and ray-casting interaction. They often rearranged document layout and placement, resulting in a dynamic and iterative process that requires constant actions such as clustering, translating, and spreading documents. Therefore, we want to investigate further these arrangement practices and strategies concerning general document organization tasks. In line with human-centered design, we aim to design interaction techniques to facilitate organizational workflows. Ultimately, we plan to establish a design framework that leverages natural human interaction to guide the design of such systems.

For this, the following research questions are worth highlighting. Specifically, **(1) strategies for creating and managing spatial layouts:** How would users cluster documents into a particular layout? How would this layout be inspected, translated, and modified? **(2) the interplay between arrangement strategies and content placement:** While the spatial layout can be constructed by arrangement actions, would document layout and placement also inform and result in arrangement strategies? **(3) general interaction style and modality:** What input modality would be preferred for arranging content? Particularly, how can physical environments and objects be utilized for arrangement actions? To understand these questions, we have conducted a participatory design study, and the results are being analyzed.

Investigating Multi-user Context (RQ4). We found that collaborating participants tend to use furniture for organizing content, some even overriding their personal preference [23]. Thus, social context seems influential in content organization and could potentially be weighted more than other factors under certain circumstances. This highlights the importance of RQ4 to explore factors considering the variety of social contexts and their impacts. Moreover, considering the presence of people in the environment and empowering multi-user scenarios would align with the core and unique value of Mixed Reality. In particular, beyond expanding display pixels to show more content, this technology could advance both interaction with computing devices and interaction among human beings.

Despite this ambition, the complexity of social context challenges the design of future MR systems, where I want to highlight two particular research avenues. First, while our previous work [23] has contributed to a collaboration scenario, follow-up investigations are needed. For instance, existing research [13] often only considered a limited number of collaborators, while real-world situations could be more complex. Besides, collaboration activities can also be dynamic with changes like collaborators joining or exiting. In this case, content placement and layout need to adapt to such an alteration, e.g., adjust the content orientation to maintain collective visibility. In addition, the placement and layout of content will likely be contextualized by the relationships of collaborators, in particular, considering the formation of distance among collaborators, or proxemics [12].

Aside from a typical collaboration scenario where collaborators share the same or similar goals, involved people could have different roles, such as in a presentation scenario. MR technology has great potential for presentation. In this case, users often engage with different purposes, resulting in distributed roles, i.e., presenters and audiences. Therefore, immersive content requires to be organized to assist not only in presenting content but also in the comprehension of information. Content layout and placement could enhance the engagement of audiences but could also undermine the experience as distractions. Understanding this spatial relation and the interplay among immersive content, the presenter, and the audience would be critical for the design of such MR systems. I am planning to approach these questions with methods like empirical studies, visualization and interaction design, and prototype development.

5 DISSERTATION STATUS AND LONG-TERM GOALS

I am currently a fourth-year Ph.D. student in the Interactive Media Lab at the Faculty of Computer Science, Technische Universität Dresden, supervised by Professor Raimund Dachselt. I have not attended previous doctoral symposiums. For this research topic, I have published four papers, including two CHI full papers [23, 25] and two Late-Breaking Works (LBWs) [6, 24], and I aim to complete the proposed research projects and the dissertation before Spring 2025. After graduation, I plan to seek research positions in academia to investigate mixed-reality interface design further and advocate for future MR-empowered workspaces.

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