Design and Evaluation of a Hybrid User Interface for Individual Sensemaking Activities

Bachelor Thesis

submitted by

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Konstanz, 26. July 2022

Abstract

Working with large data sets, extracting important information, and making sense of multiple data sources has long been a part of our daily lives. These activities and processes are referred to as sensemaking. Humans tend to arrange content spatially and attribute meaning to different locations in their work space while working on such sensemaking tasks. Because of the device's limited screen size, organizing content spatially has become more difficult as digital devices such as laptops have become more prevalent. Augmented Reality creates a space in which users can freely arrange and place virtual content while remaining aware of their surroundings. While Augmented Reality offers a promising setting for sensemaking, it is still in its early stages and faces some limitations. These limitations could be compensated for by combining it with a hand-held device such as a tablet. Therefore this paper will describe the design and evaluation of a hybrid user interface designed for individual sensemaking activities in order to perform a usability study to gain insight into virtual content placement and user's sensemaking workflow with a hybrid user interface using Augmented Reality.

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1 Introduction

Whether you are working on a project or studying for an exam at university, sensemaking is a process that everyone goes through in their daily lives. People gather information individually or collaboratively, arrange it, and gain new knowledge along the way. Making sense of unknown facts in order to attain a certain goal or answer task-specific questions is what sensemaking is all about [4, 7, 5, 6]. It encompasses not just information acquisition and knowledge, but also creativity and cognitive skills [14]. We tend to use our environment while working with large data sets to spatially organise content and provide meaning to groups created during the process [28, 2, 1, 4, 8, 10]. Therefore, Augmented Reality offers a promising environment for sensemaking, allowing users to freely arrange virtual content in space while remaining aware of their surroundings and collaborators.

In order to examine virtual content placement and user workflow in Augmented Reality, this work proposes a hybrid user interface prototype tailored for individual sensemaking activities. The thesis's content is structured as follows: The theoretical background of this work will be discussed in Chapter 2. Various sensemaking models will be addressed and analyzed, as well as hybrid user interfaces will be introduced. Then, Chapter 3 will quickly discuss four related works that propose answers to the digital device screen size problem, before focusing on two studies that investigate document layout and placement strategies in Augmented Reality. The system's design concept and features will be detailed in Chapter 4, while the implementation specifics, including hardware and software information, will be discussed in Chapter 5. Finally, Chapter 6 will detail the user study that was conducted, as well as the results that were gathered and presented in relation to the theoretical foundation, prior work, and findings. This chapter is guided by three main research objectives and will also discuss the current system's limitation and future work.

2 Theoretical Foundation

Sensemaking can be defined as the process of gathering and organizing unfamiliar data in order to make sense of it [14]. It entails not only the collecting of relevant information but also the exchange of expertise with collaborators [12, 15]. Sensemaking can involve a group of individuals and rely on teamwork. Only the individual aspects of sensemaking will be examined in this thesis. In Section 2.1, two different models defining the sensemaking process will be discussed in order to better comprehend the term sensemaking and what it incorporates. And Section 2.2 will discuss Hybrid User Interfaces and their applications briefly.

2.1 Sensemaking

In the past decade different research came up with models seeking to describe the sensemaking process and its activities [4, 7, 5, 6]. Two of these models, as well as the associated work, will be detailed in this section, with a focus on the representation of sensemaking activities and comprehension of the included phases.

2.1.1 The Cost Structure of Sensemaking

Russell et al. [17] published the Cost Structure of Sensemaking in 1993, in which they examined several sensemaking tasks and developed a model (Figure 2.1) of the cost structure of sensemaking.

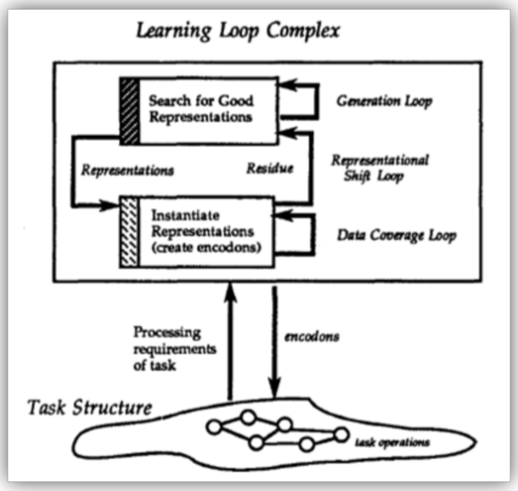

Figure 2.1: Visualization of the learning loop complex by Russel et al., 1993

They stated that any person performing a sensemaking activity has multiple resources, which can be both internal cognitive and external. These resources assist in the storage and processing of information. Methods for carrying out the sensemaking activities were mentioned and described as processes requiring a specific resource. A case study was conducted with a laser printing educational course for Xerox technicians, in which they were required to make sense of information regarding various laser printers. Participants in this case study gathered and structured information about twenty-one different laser printers, as well as created groups of common terms, functions, and ideas to help them understand laser printers in general. They discovered that a so-called learning loop complex can be detected throughout this process. During this loop, participants go through three main processes (see Figure 2.1) to lower the cost of the operations needed for sensemaking:

1. **Search for a representation**: A representation is searched which best represents the key aspects of the data retrieved. The search procedure is hereby described by the generation loop.

2. **Instantiate representation**: During the generation loop, important information is added to the representation. Encodons are potential schemas that emerge during the data coverage loop.

3. **Shift representation**: The representation can change during the work process. With new data being added, the representation is adjusted to further reduce the cost of the operations performed. During this process data or representations can be left out or not needed (Residue). During the representational shift loop important information which does not currently fit the representation leads to its shift. Along the way, schemas can be expanded to include additional data, and groups can be split up or combined.

A fourth process outside of the learning loop complex has also been identified:

4. **Consume encodons**: The encodons that emerge from the learning loop complex are then used to carry out task-specific operations in order to achieve the sensemaking goal. Task requirements and goals, as well as unexpected events, might cause schema and representation revisions and a new pass through the learning loop complex.

Sensemaking was therefore described by Russel et al as "[...] the process of searching for a representation and encoding data in that representation to answer task-specific questions."

2.1.2 The Sensemaking Process and Leverage Points for Analyst Technology as Identified Through Cognitive Task Analysis

Pirolli et al. [13] conducted research in order to better understand the sensemaking process and identify leverage points for improvement. Various schemas were utilized to organize the data, according to an interview with several analysts. A schema was described by Pirolli et al. as a "[...] set of patterns from extensive experience [...] built up around the important elements of their tasks [...]." These conceptual schemas are sometimes important in some so-called sensemaking tasks.

According to Russel et al. [17], sensemaking is altering and adjusting the representation created from raw data. This re-representation can be done in the analyst's head or with the support of paper- or computer-based systems, according to Pirolli et al. The model in Figure 2.2 was built using the Russel et al. model outlined in section 2.1.1 as well as the results of the cognitive task analysis conducted as part of the study.

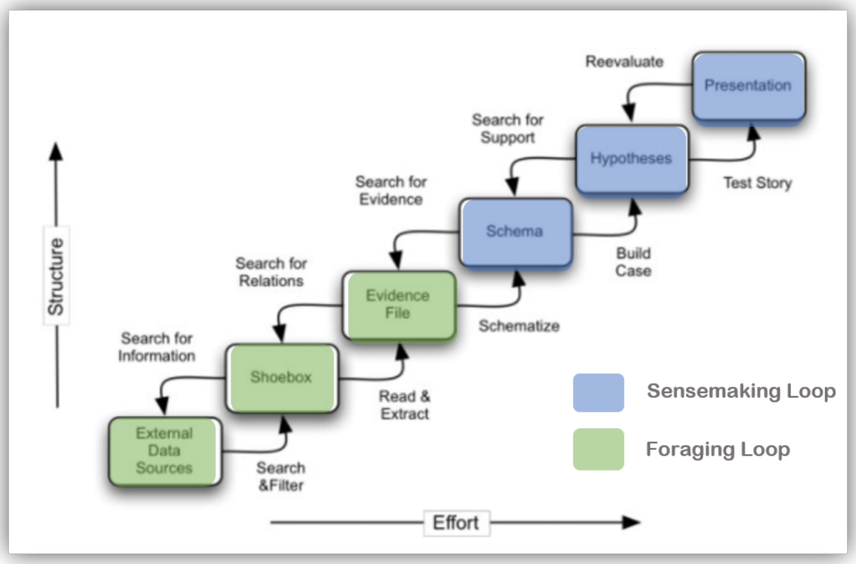

Figure 2.2: Model of sensemaking for intelligence analysis

The rectangles reflect the approximate data flow observed across numerous analysts during the sensemaking process, and the arrows linking the rectangles show the process flow. Both are organized by the degree of effort, which comprises the amount of time and operations required to complete the task, as well as the degree of information structure. This model is described as having several loops involving different data types and illustrating the transformation of the raw data that analysts start with to their presentable results. The following are the different data flow types (1. being raw data and 6. being results):

1. **External data sources**: Set of data available to the analyst. Often consisting of large raw text files.
2. **Shoebox**: A selection of data from external data sources. The data is first filtered in the shoebox, which only contains data that the analysts consider useful.
3. **Evidence file**: Individual snippets of important information from the filtered data are extracted.
4. **Schemas**: The collected snippets are grouped and placed into a representation that can be utilized to quickly answer the sensemaking tasks.
5. **Hypotheses**: In a preliminary representation, the possible answers acquired with the help of the schemas are then backed up by appropriate arguments.
6. **Presentation**: The last stage of the representation, which can be utilized to report and communicate the results.

The activities in the process flow can be separated into two groups, which are represented in the model by two major loops:

1. **Foraging loop**: Activities centered around finding information, searching for key aspects and filtering it down to the essentials. It also includes reading and extracting the most important bits of data into a feasible schema.

2. **Sensemaking loop**: An interactive process for creating the optimum mental model for the data gathered during the foraging loop. The mental model aids in making sense of the data and supporting the findings.

According to Pirolli et al., the model's information flow can be driven by two sorts of processes: bottom-up and top-down. The following activities are classified as bottom-up processes:

1. Search and filter
2. Read and extract
3. Schematize: Representation of the data in a schema. This can be visualized in the analyst's head or depicted using paper or computer-based tools.
4. Build case: A theory is constructed using the evidence acquired.
5. Tell story: The results and findings are communicated or presented.

Another set of activities was mentioned for the top-down process:

1. Re-evaluate
2. Search for support: Re-examination of schemas containing basis facts.
3. Search for evidence: Re-examination of already collected evidence and search for new evidence to support new theories.
4. Search relations
5. Search for information: New theories encourage the analyst to revisit the raw data in search of new or overlooked information.

2.2 Hybrid User Interfaces

In 1991 Feiner et al. described an interface design where displays are being combined with interaction device technologies [3]. Technologies which have a low resolution provide a large field of visual and interactive possibilities, whereas technologies with a high resolution can display concentrated information. It was discussed that both types of technologies can be combined to form a so-called hybrid user interface, which enables the users to work with both interfaces simultaneously while benefiting from the strong-points of each.

With the current trend in computing being to minimize the size of technologies, computer's interfaces and screens grow smaller. This lead to interface designs facing serious consequences and limitations. Since portable interfaces such as smartphones don't seem to get physically bigger in the future, the possibility to make use of virtual worlds has been mentioned. Head-mounted displays thereby provide an environment with a large field where virtual content can be displayed and interacted with. In their paper the development of a prototype hybrid user interface for tasks that benefit from precise work on a small space and as well from providing a larger virtual space, was described.

3 Related work

Using space to organize, form spatial frameworks, and categorize unknown data sets has been studied as a way to shape ideas and thoughts throughout the sensemaking process [28, 2, 1, 4, 8, 10]. Humans have used pen and paper methods to retain their work for over a decade [18], and they have always played an essential role in brainstorming and sensemaking activities. People utilize their surroundings to organize physical papers in a spatial layout [11]. Paper-based approaches are becoming less popular as digital solutions take their place. These digital tools include features like searching, copying and pasting, and dealing with larger data sets. Despite the fact that these interactive programs could aid in the sensemaking process [28], the most of them are limited by screen size. Because of this constraint, using space as a spatial memory approach becomes difficult. Various techniques to solving this problem have been proposed in the past [1, 29, 32, 31]. The Sections 3.1 - 3.3 will briefly discuss these approaches.

New technologies like Augmented and Virtual Reality allow users to generate sophisticated representations [8, 9, 10] and offer new interaction possibilities. An approach to the screen size problem using a Virtual Reality application will therefore be discussed in Section 3.4. But in contrast to Virtual Reality, Augmented Reality allows users to be more aware of their surroundings while also enhancing their working environment with virtual content [16, 8, 10, 19]. As a result, Augmented Reality has the potential to build a promising sensemaking environment. Therefore the focus of this chapter will be on two papers discussing the content arrangement and layout developed when performing a sensemaking task in Augmented Reality, which will be detailed in Sections 3.5 and 3.6.

3.1 Space To Think

To address the screen size problem of digital devices, Andrews et al. [1] employed numerous big, high-resolution displays. This layout enables users to compare more content at once by placing it side by side. When using a single monitor, users are more likely to conduct a lot of context shifts while switching between taps, making it more difficult to compare and navigate large data sets. The user may coordinate themselves and rapidly re-find specific bits of information thanks to the content's placement on different screens. Another important feature was the ability to quickly scan the available displays for relevant data sets and get a sense of the work that had previously been completed. According to Andrews et al.'s user study, the space accessible through the various displays was largely utilised as external memory and storage capacity. The space was therefore divided and sorted into several partitions, such as relevant content, irrelevant content, and documents that had still to be examined. The visibility and accessibility of these partitions varied. Users filtered out information on a display that was further away while putting relevant information right in front of them. It was also shown that the majority of users utilised a designated work zone. This work zone was usually in the middle of the screen and served as the main focus while performing a task.

3.2 RAMPARTS

A user research was conducted using a system called RAMPARTS [29], which was designed for collaborative criminal analysis. Using several spatially aware mobile devices, this solution enables quick and easy information sharing amongst collaborators. As a result, the screen size was shared between the various devices, resulting in a bigger working area for the users. Participants were able to share private information with other nearby devices, allowing content to be shared among numerous devices. This allowed for the creation of intricate arrangements and structures both within and connected between the different devices. The information was displayed on sticky notes that could be rearranged and moved around at will. Because the components of the system are spatially aware, moving them about freely in real space causes the content to adjust correspondingly while maintaining the correct connections.

3.3 When Tablets meet Tabletops

The influence of tabletop size on collaborative cross-device work was investigated using the system proposed by Zagermann et al. [31]. Each participant had their own tablet as a personal work area for the duration of the study. They were able to use the tablet to examine and interact with documents from the database, as well as share them with their collaborators. Documents could be shared by sending them directly to collaborators' tablets or by displaying them in the form of box containers on a shared tabletop.Every content added to the tabletop could be removed or reopened on the participants personal tablets. Each participant was given a unique color, which was shown on every shared document to indicate where it came from. A lasso tool could be used to reorganize and group material on the tables. The tablets functioned as a personal work space and information source, while the tabletop environment provided an overview and a means of communication among the participants.

3.4 Immersive Space To Think

Lisle et al. [8] adapted the idea behind the system Space To Think outlined in Section 3.1 to a Virtual Reality environment. Space To Think's features were altered to be included in the Immersive Space To Think. This environment increased the amount of available space all around the user, allowing documents to be inserted and laid out in a 3D environment, allowing for more sophisticated structures and representations. Users could now take a step back and look at an overview of the layout they've built, and instantly recall the individual content's location by giving meaning to virtual locations. The virtual reality concept was well received by the participants, who claimed to have a better knowledge of the subject at hand and better thought organization than in the desktop environment.

3.5 Investigating Document Layout and Placement Strategies

Luo et al. [10] focused their paper on three research questions connected to collaboration and content placement in Augmented Reality since it provides a potential setting for sensemaking and brainstorming work:

1. How is content placed in AR for sensemaking activities?
2. How do room features and furniture affect user's content placement in AR?
3. How do multiple users coordinate the space and place AR content together?

A study with eight participants was undertaken to compare the arrangement of virtual material in two different room settings. Participants were asked to categorize images in Augmented Reality as part of a collaborative card sorting game. A low-level sensemaking assignment was chosen as the task. Participants were free to move and group content to meet the various categories that had been generated. At the start of the study, the photos were uniformly placed throughout the room. The experiment was set up with two research conditions: a fully furnished room and a room with less furniture. Luo et al. identify different patterns and arrangements of content in the collaborative Augmented Reality environment based on the data gathered. There were three basic layout patterns for gathering and organizing the data:

1. **Panoramic-strip**: The images were primarily horizontal and formed a semicircle around the user. The images were not always set out in a continuous manner, and gaps between the several groups generated inside the strip representation were occasionally identifiable. Figure 3.1 A illustrates this pattern.

2. **Semi-cylindrical pattern**: The photos were arranged horizontally as well as vertically. The area between the floor and the ceiling was used to divide the room into two primary groupings, each having its own sub-categories. The data was organized in a cylinder pattern, which was more compact and dense than the panoramic-strip layout. Figure 3.1 B illustrates this arrangement.

3. **Furniture-based distribution**: The images were arranged in various clusters across the space, guided by the real-world furnishings. This pattern was discovered to be combined with the previously listed patterns. The contents spatial relations were frequently used to separate the clusters into sub clusters. Figure 3.1 C illustrates this pattern.

Figure 3.1: The layout patterns identified during the study: Panoramic-strip (A), Semi-cylindrical pattern (B) and Furniture-based distribution (C).

3.6 Where Should We Put It?

Luo et al. published a paper [9] as a continuation of their prior work [10], which goes into greater detail regarding the various layout and placement techniques identified. A user study involving twenty-eight individuals was conducted as part of this project. The purpose was to look into the impact of the office environment on Augmented Reality sensemaking and brainstorming, and to provide design implications for Augmented Reality sensemaking and brainstorming applications. Two physical environments (fully furnished and side-furnished rooms) and two work styles (collaborative and individual) were explored. The participants were given two sets of cards, each with an image, a title, and a brief explanation, to assess and organize into a systematic layout.

Figure 3.2: Both room settings used for the study: Fully-furnished (A) and Side-furnished (B).

Luo et al. discovered that the furniture was required by the participants in their study since it appeared to aid their sensemaking and collaboration. They also discovered four main steps in the sensemaking process that are linked to foraging and the sensemaking loop:

1. **Planning stage**: Participants examined the data and created an overview with different grouping and organization options. The overview approach, in which all the data is viewed before grouping it, and the iterative approach, in which groups are constructed based on the first data viewed and the remaining cards are added to them repeatedly, expanding and altering them, were identified.

2. **Structuring stage**: The main categories into which the cards are sorted were created.

3. **Refinement stage**: Following the grouping of the majority of the cards, new subcategories were developed, and existing clusters were shifted and altered.

4. **Finalization stage**: The participants went over their categories and changed them for a better visual representation in this phase.

Phase 1 was recognized as part of the foraging loop, while phases 2–4 were identified as separate sensemaking tasks as part of the sensemaking loop.

Furthermore eight different spatial layouts were mentioned:

1. **Grid-like**: Clusters were created with a gird structure and possible overlapping content (Figure 3.3 A).
2. **Cylindrical**: Groups were laid out in a circular manner around the participants. It can be distinguished between two circular patterns, which were discussed in Luo et al.'s previous work: panoramic-strip and (semi)-cylinder. (Figure 3.3 B and Figure 3.4 A).
3. **Furniture-anchored cylindrical**: Participants used the physical environment to create cylindrical arrangements. These arrangements were often placed in front of furniture unconsciously (Figure 3.3 C).
4. **Furniture-aligned cylindrical**: The clusters were laid on top of physical markers, such as furniture and room areas and in a cylindrical manner. This pattern is more furniture dependent than the furniture-anchored pattern (Figure 3.3 E and Figure 3.4 B).
5. **Vertical surface furniture based**: The imaged were laid out into clusters only using vertical surfaces on furniture such as cabinets and whiteboards (Figure 3.3 F).
6. **Omni-furniture-based**: The participants used all the surfaces and physical surroundings while laying the

content both in a vertical and horizontal way (Figure 3.3 H and Figure 3.4 D).
7. **Horizontal surface furniture-based**: Tables were used as horizontal surfaces to separate and organize the different images (Figure 3.3 6 and Figure 3.4 C).
8. **Canvas-centered**: Mostly walls and whiteboards were used as a sort of canvas to organize the clusters (Figure 3.3 D).

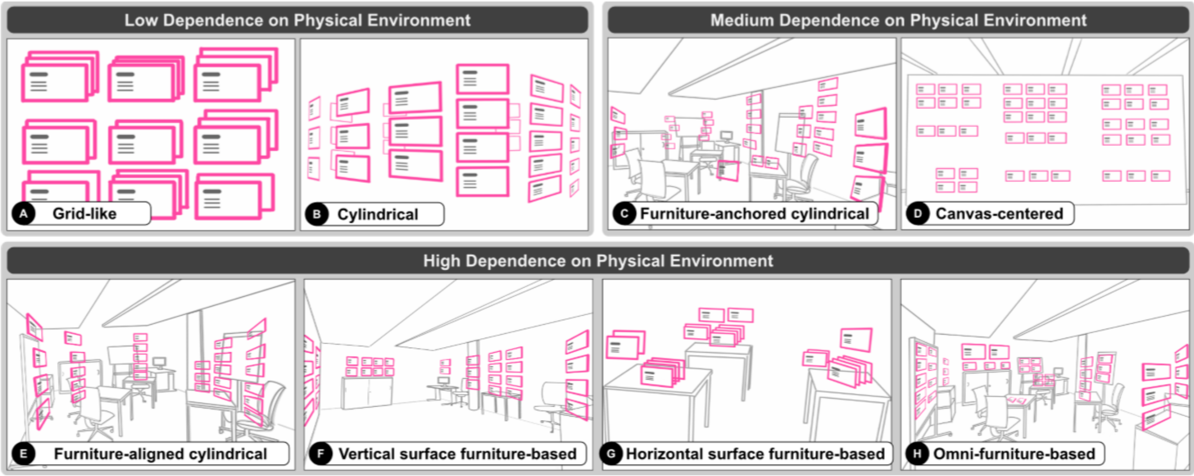

Figure 3.3: Illustrations showing the final layout patterns identified as part of the study.

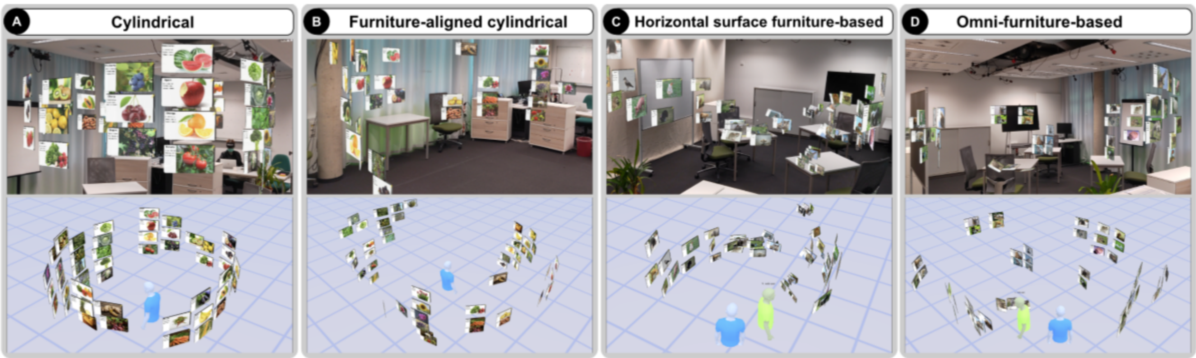

Figure 3.4: Four examples of final layouts produced by participants.

Participants working individually favored none of the two alternative room settings, however it was discovered that with more furniture in the room, participants tend to employ more of the physical surroundings as they lay out the content.

4 Design

This chapter describes the design and features provided by the prototype created as part of the Bachelor Project [21]. It was designed to support sensemaking tasks and to help analyze content placement and workflow in Augmented Reality. Section 4.1 will outline the general concept as well as the basis used for the design decisions. Then, an overview over all the features provided will be given as part of section 4.2.

4.1 Concept

As part of the Bachelor Seminar [22], the sensemaking foundations were discussed, mentioning both the individual (Section 2.1) and collaborative aspects. Based on the information gathered seven individual and six collaborative sensemaking requirements were deducted aiming to create an environment which would best support collaborative sensemaking activities:

I1: Be able to search and retrieve information.
I2: Option to filter information.
I3: Documents should be readable.
I4: Option to extract information.
I5: Possibility to create a schema or representation.
I6: Be able to mark existing relations between bits of information.
I7: Representation and schema should be changeable in every state.

C8: Option to create an external and individual representation.
C9: Allow the co-existence of multiple representations.
C10: Possibility to mark sensemaking trajectories.
C11: Be able to exchange documents and content among collaborators.
C12: Option to communicate with collaborators (Social awareness).
C13: Possibility to view the actions and work of the other collaborators (action awareness).

Based on these requirements five related work: Space To Think [1], RAMPARTS [29], Immersive Space To Think [8], When Tablets meet Tabletops [31] and Document Layout and Placement Strategies [10] (Section 3) were analyzed and compared. As a result the system proposed by Zagermann et al. [31] showed to fulfil the majority of the requirements and was therefore used as basis for the features of the prototype developed as part of the Bachelor Project. The idea of employing a Hybrid User Interface to aid collaborative communication while still offering a individual work space arose from this paper.

Hybrid user interfaces offer the possibility to combine smaller technologies such as tablets and smartphone with Augmented Reality as outlined in section 2.2. Head-mounted displays such as the Hololens 2[1] enable the users to work with virtual content while still being aware of their surroundings. Although this facilitates integrating digital applications in the already existing environment, the Hololens still faced some limitations. Due to this

[1]https://www.microsoft.com/en-us/hololens/buy (18.05.22)

technology being fairly new, some features are currently still being optimized. Reading with the Hololens can be challenging and exhausting due to the low resolution and being strenuous for the users eyes. Writing in Augmented Reality can be very time consuming and frustrating due to the needed hand recognition. To compensate for these weak-points the Head-mounted display can be combined with smaller technologies which offer better interaction and resolution for reading and writing. Therefore a hybrid user interface would provide a promising environment for work in Augmented Reality.

Firstly, a design concept was described using Figma[2], a vector graphics editor and prototyping tool for Windows (Figure 4.1). The prototype would consist of two devices: a tablet and the Hololens 2 as Augmented Reality device. The tablet hereby serves as a data source providing the necessary information and individual work space, whereas the Head-mounted display provides an environment were the information displayed on the tablet can be added to and arranged in space to organize it and communicated the findings. This initial design aimed to fulfil both individual and collaborative requirements which was later on reduced to only include the individual aspects due to time and scope restrictions.

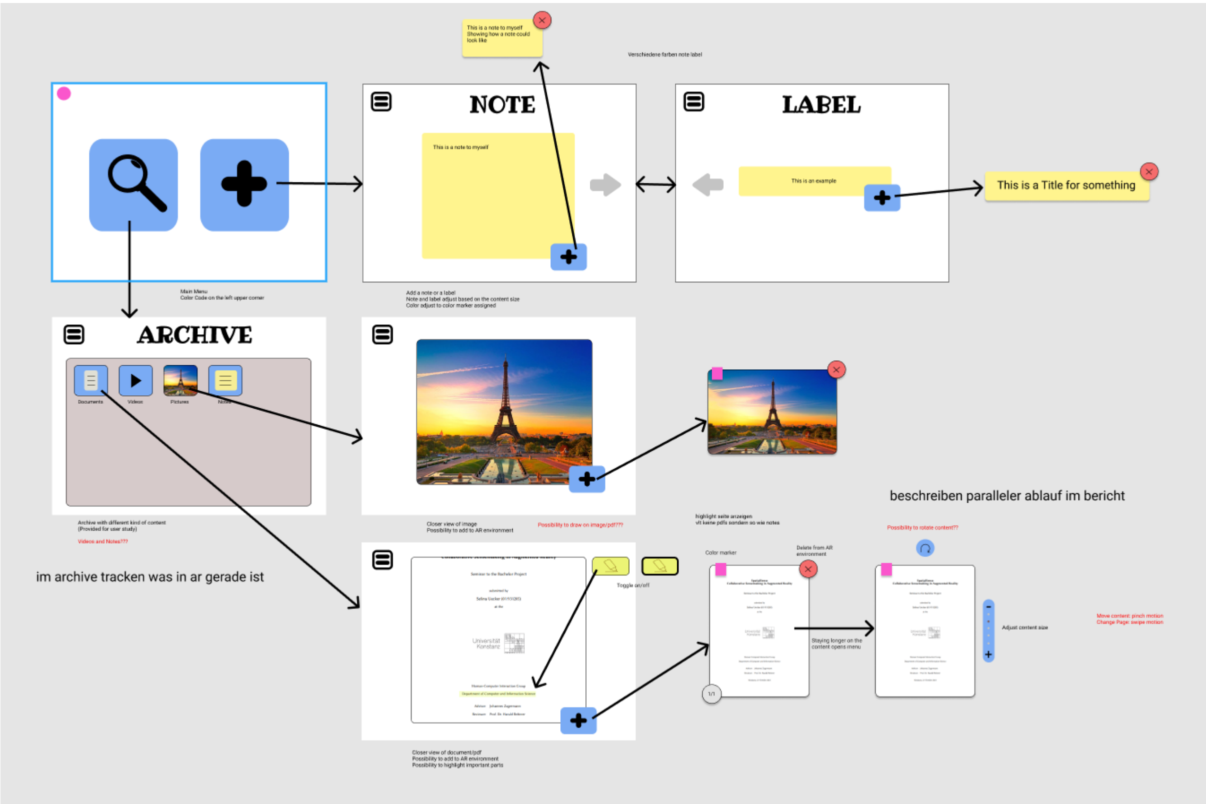

Figure 4.1: The first design for the prototype created with Figma, showcasing the different features. This design still incorporates the collaborative aspects.

[2]https://www.figma.com/ (18.05.22)

4.2 Features

The prototype provides multiple features for working on a sensemaking task. The concept was adjusted to fit the study task and research objectives described in Section 6.1 and 6.2 as part of this Bachelor Thesis.

4.2.1 Tablet

The interface was implemented in a dark mode. After implementing the interface with the white-blue color scheme proposed in the initial design shown in Section 4.1, it was thought to be too blinding when used with the Hololens 2. The dark design was also chosen to not further exhaust the users eyes while working with the Head-mounted display and to provide a better contrast between the text and background for better reading.

Figure 4.2: The four main interfaces provided by the tablet application: Archive (A), Text view (B), Menu (C) and Image view (D).

The different tablet interfaces can be navigated through the menu shown when first starting the application (Figure 4.2 C) and the back button located in the left upper corner can be used to return to the previous page. The tutorial button serves as a quick overview for the study setting and will not be discussed in this Section.

In the archive users can find provided content for the sensemaking task (Figure 4.2 A). Two types of content can thereby be added: text files and images. Each content displayed in the archive consists of an image (a standard document image if it is a text file) and a content name underneath. With the help of four filters located at the bottom right corner of the interface, users are able to hide and display specific subsets. Two filters focus on the content type (image, text files) and the other two on the interaction with the Hololens. Since every content visible on the tablet can be added to the Augmented Reality environment seen through the head-mounted display, these two filters were aimed to facilitate keeping track of content which has already been added and content which hasn't been added yet (filter names: Added content, Non-added content). Content which has already been added at least once will be marked in the archive with a green Hololens icon. Additionally the content visible in the archive can be viewed in more detail by pressing on the corresponding image.

Depending on the content type a different interface will open. For images the image view will be displayed (Figure 4.2 D) and for text files the text view (Figure 4.2 B). In the text view the full text with the corresponding file name as title, is displayed in a scrollable field. For the image view the image previously visible in the archive is displayed in a bigger version without the content name. Both content types can be added multiple times to the Augmented Reality environment by clicking the button in the lower right corner of the interface.

User have the possibility to add their own input by creating notes and labels through the interfaces provided by the tablet application (Figure 4.3). These interfaces can be accessed through every interface shown in Figure 4.2: the menu, the image view, the text view and the archive, by clicking the corresponding buttons.

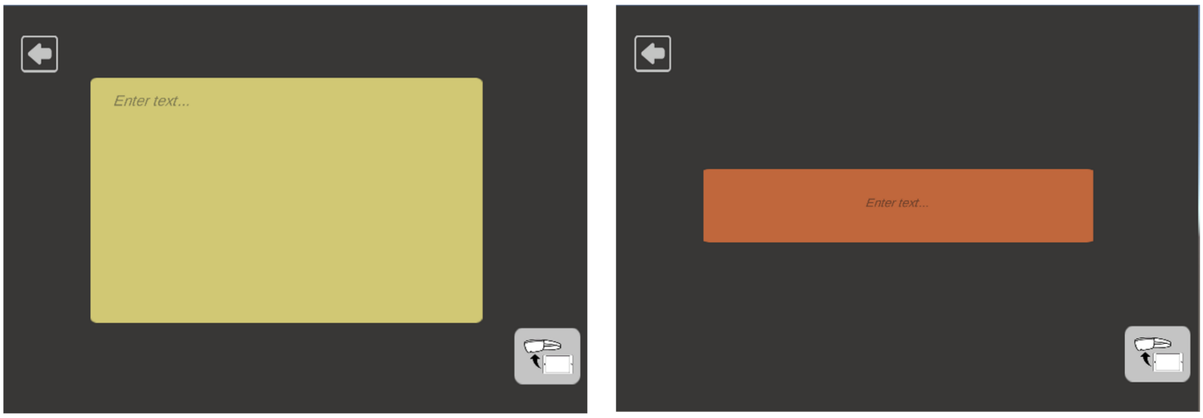

Figure 4.3: Interfaces enabling the user to create notes (left) and labels (right).

A dummy note or label will be displayed and after pressing on it a keyboard will be opened for the user to add their input in. Notes have a yellow color and expand vertically when adjusting to the input, while the labels are red and expand horizontally. Both labels and notes can also be added to the Augmented Reality button by pressing the same button as described in the previous part.

4.2.2 Hololens 2

The content added to the Augmented Reality will be spawned in front of the user at an interaction distance and can then be seen through the Hololens. Every content added is displayed as a 3D object for better integration in the physical environment and possesses a red close button in the right upper corner to remove it from the

Augmented Reality environment. Removed content will not be seen with the head-mounted display anymore but can be re-added using the tablet if required.

Content in Augmented Reality can be interacted with using the standard interaction methods provided by the Mixed Reality Toolkit[3]. Content can be moved around freely by using the one hand pinch motion (Figure 4.4 A and B) or rotate and scale it with the two hand pinch interaction (Figure 4.4 C and D). It can be distinguished between two different interaction types: far and near interaction. With the near interaction content can be directly manipulated with the users hand (Figure 4.4 A and C) while the far interaction manipulated content by using a ray emitted from the users hands (Figure 4.4 B and D).

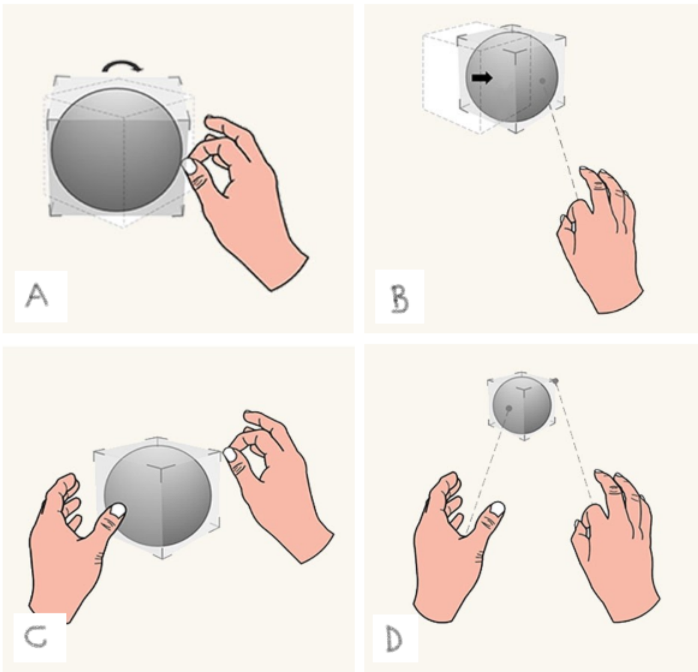

Figure 4.4: The four different interaction methods provided by the system: Near pinch (A), Far pinch (B), Near scale/rotate (C), Far scale/rotate (D) [24, 25, 26, 27].

Different representations can therefore be created by grouping, arranging and adjusting the content in Augmented Reality as seen in a sample representation created in Figure 4.5.

[3]https://docs.microsoft.com/en-us/windows/mixed-reality/mrtk-unity/?view=mrtkunity-2021-05 (19.05.22)

Figure 4.5: An example of a representation created with the prototype in Augmented Reality.

Some functionalities were intentionally left out in order to study the sensemaking process and tailor the prototype to the research aim. To differentiate the functionality of the two devices, copying and pasting content in Augmented Reality was not provided. The tablet should be used as a data source, while the Hololens should only be used to create representations and understand the content. The highlight function, which was part of the Bachelor Project, was replaced with the filter function. Because the clues provided only consisted of view phrases and often just convey the pertinent information, the highlights were deemed more disturbing then useful. This was also packed up by the results of the preliminary study content as part of the Bachelor Thesis where the participants did not make use of the highlighting function (Section 6.2.4).

5 Implementation

This chapter explains the Hybrid User Interface prototype's implementation and can be found in further detail in the Bachelor Project report [21]. The hardware utilized for this system is first detailed in Section 5.1, and then the software needed for implementation is discussed in Section 5.2.

5.1 Hardware

The system consists of a head-mounted display that provides an immersive Augmented Reality environment, as well as a mhand-held device that provides content to users.

5.1.1 Head-Mounted Display

A hardware that could give an immersive experience was chosen to allow people to be aware of their surroundings. A device that does not restrict the users' motions would be ideal for improved interaction and unrestricted movement. As a result, the Microsoft Hololens 2 was selected[1]. This technology allows the user to view and interact with virtual content while remaining aware of their surroundings. It also does not rely on any connections, allowing users to roam around freely. The Hololens 2 has a 43-degree x 28.5-degree field of vision, as well as head, eye, and hand tracking[2].

5.1.2 Hand-Held device

The system was built using an iPad Pro 11" 2021[3] because of its lightweight design, which allows people to work with it for extended periods of time. The decision to use a table rather than a smaller device like a smartphone was made during the first design phase. The initial concept was intended to provide longer text files for the user to peruse as well as a highlight function. The tablet's larger screen was chosen to allow for easier viewing of text files and interactions with the highlighting function. Because the user study's clues were made up of view sentences, the highlight function was removed from the final prototype. The larger screen also provides a faster overview of the archive's content and could accommodate other capabilities such as e-pencil interactions in future work.

[1] https://www.microsoft.com/en-us/hololens/buy/ (19.05.22)
[2] https://www.microsoft.com/en-us/hololens/hardware (22.05.2022)
[3] https://www.apple.com/de/shop/buy-ipad/ipad-pro (22.05.2022)

5.2 Software

The system is made up of two different applications that are deployed on both devices and were created with Unity[4], a cross-platform game engine from Unity Technologies that combines a graphical interface with C# scripts. A Unity library developed by the University of Constance's Human-Computer-Interaction group was used to communicate between the two programs. Colibri[5] allows for cross-device communication as well as 3D object synchronization via networking.

[4]https://unity.com/ (13.01.2022)
[5]https://gitlab.inf.uni-konstanz.de/ag-hci/research/colibri/colibri-unity (22.05.2022)

6 Evaluation

This chapter will focus on how the results of the user study were evaluated. To begin, three research objectives and questions will be addressed in the user study mentioned in Section 6.2. The findings from the user study will be presented in Section 6.3, while Section 6.5 will go into greater detail concerning the limitation encountered. The results will be discussed in Section 6.4 in relation to the research objectives, with the goal of answering the questions. Finally, section 6.6 will present possibly improvements for the prototype and future research subjects.

6.1 Research Objectives

The purpose of this thesis is to examine how users interact with the system and perform sensemaking activities with it. The goal was broken down into three research objectives, each with a set of research questions that this thesis aims to answer:

Research Objective 1: Spatial Arrangement and placement of Content in Augmented Reality
- How is content spatially arranged and laid out in augmented reality?

Research Objective 2: Workflow
- How are the tablet and Hololens 2 being used to complete the study task?
- How can the workflow be mapped to the sensemaking process?

Research Objective 3: User Experience
- Does the system aid the users in their tasks?
- Does the prototype support the sensemaking process?

6.2 User study

To address the previously mentioned research objectives, a user study with thirteen participants was conducted. There was no requirement for prior knowledge, and the evaluation focused on the interaction with the system as well as the strategies utilized to complete the task. As a result, an exploratory study with no conditions employing the prototype and a pre-defined task was chosen.

6.2.1 Participants

The study included thirteen participants, ranging in age from 22 to 32 years old (10 men and 3 women). They were made up of twelve students: six master's students, two bachelor's students, a master's student in biological science, a master's student in math, a master's student in economic education, and a master's student in speech and language processing, as well as one Ph.D. student in computer science. There were no physical limitations among the participants. One participant had ADHD, while another had color blindness, the latter had no effect on the study's findings. They have all claimed that they spend more than 5 hours every day working with technological devices. Participants were asked to rate their technological competence (Poor, below average, average, above average, excellent). Seven participants assessed their abilities as exceptional (P1,P3,P6,P8,P10,P11,P13), five as good (P2,P4,P5,P7,P12), and one as average (P9). Only one of the participants (P9) has never worked with Augmented Reality before; the rest had seen it in applications like Pokemon Go and IKEA Place. Regarding previous use of the Hololens 2: six individuals (P2,P3,P5,P8,P11,P12) have used it before as part of their own Master/Bachelor Thesis, other university-related studies or courses, or research, whereas the other seven have never used it before (P1,P4,P6,P7,P9,P10,P13).

6.2.2 Procedure

The participants were greeted, informed about the current state of the risk assessment (including the precautions required due to the current pandemic), and given a number of documents, including an informative text about the study procedure and general information, a consent form, and a demographic questionnaire. The core concept of Augmented Reality, as well as the next phase, were discussed after the participants read, filled out the documents, and asked additional questions. During the explanation, a CleanBox[1] was used to cleanse the Hololens 2 and the tablet. The participants were then instructed to remove the Hololens 2 from the CleanBox on their own and modify it to their preferences. Before the head-mounted display could be used, participants had to do an eye calibration, which required them to follow different diamonds with their eyes without moving their heads. This allows the Hololens 2 to be entirely customized to the wearer's features, reducing any potential discomfort. The participants were then instructed to read through a tutorial consisting of a wizard program on the tablet. The basic interactions with the Hololens 2, such as the single hand pinch motion, two hand scale and rotate motion, and the distinction between far and near interaction methods, were explained. A description of the features supplied by the prototype was also provided. The participants were then instructed to stand in the starting position and test the prototype using dummy data unrelated to the research task. During this phase, participants were encouraged to ask questions and test out all of the features so that they felt comfortable interacting with the prototype. The recordings were started after the training session ended, and the participants were requested to situate themselves at the start point and read the research task. Each participant got 30 minutes to solve a murder mystery and answer 5 related questions using the prototype while remaining in the designated area. If the participant believed to have the answer in a shorter length of time, the assignment could be interrupted sooner. Halftime and the remaining 5 minutes were announced, and any more questions about technological difficulties were welcome. The participants were urged to think out loud in order to better understand their cognitive processes and capture more notes. In a following semi-structured interview, the participants were invited to present their findings using the prototype representation and to answer some additional questions about their experience and work strategy. Finally, the participants were requested to complete a User Experience Questionnaire (UEQ) in exchange for a monetary reward of ten euros. The user study took about an hour to complete, with the study task taking between 22 and 30 minutes to complete. Five of the ten participants got all of the questions right, four got one wrong, one offered incorrect responses, and the remaining two only got one question right.

[1] https://cleanboxtech.com/ (12.05.2022)

6.2.3 Apparatus

The user study was conducted in a room where participants were free to move about in a designated area (Figure 6.1 and Figure 6.2). This location was marked with black tape and such as the location for start of the user task. The attendees were free to use the two tables and two chairs that were provided in the room. The questionnaires and interview session were conducted on one of these tables. A closet and trashcan were also included in the room arrangement. On one of the room's walls was a large whiteboard. Participants were not permitted to use it in the typical manner (with pens), although it was frequently used as a focal point (See Section 6.3.1). The room arrangement was chosen to provide the appearance of a real work environment in which participants can freely interact with the provided furniture and work with the full space available.

Figure 6.1: The room and furniture setting used for the user study from two different perspectives. The crosses in the floor and whiteboard are the start points for the user study.

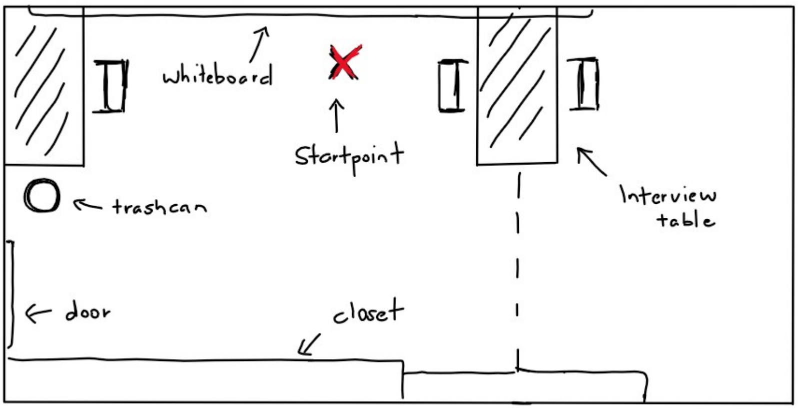

Figure 6.2: A sketch of the room used, with labeled furniture and start point.

6.2.4 Task

A sensemaking assignment was chosen for this user study in order to gain insight into the process while completing a real-world activity. A murder mystery suggested by Standorf et al. [20] was used. Additional content in the form of images (see Appendix) was supplied to give participants a visual representation of the questions asked and to aid them in their thought process. The participants had to filter out irrelevant data and decipher the main plot, which was concealed by a second set of events that misled them. The murderer, the murder weapon, the time and place of the murder, as well as the motive, all had to be discovered and provided to the study conductor. In previous sensemaking research, such as Zagermann et al. [31] and Wozniak et al. [30] this task was also used.

Murder mystery task:

You are a detective working at the homicide department. This morning a new case was lying on your desk:
A certain Mister Kelley was found dead with clues suggesting it could be a murder case.
In the case file (Archive) you will find different clues and images that could help you solve this case.

Now it is your goal to find answers to the following questions:
- Who is the murderer?
- What was the murder weapon used?
- When did the murder happen?
- Where did the murder take place?
- What was the motive?

Prior to the user study, a preliminary study was conducted utilizing only the clues provided by the murder case to determine which features were used and how much time the users needed to complete the murder mystery, order to plan the study process. The three participants were students who volunteered to participate in the task. The clues were cut out individually and placed on the table for the participants to use and move around. Notes (green squares), labels (red rectangles), and a highlighting pen could also be used to mimic the prototype's functions (Figure 6.3). The goal was to discover new features, reduce existing ones to the bare minimum, and gain a sense of how long it would take to complete the task. Because the clues were already compact, the participants did not utilize the highlighting pen; instead, they used the label and notes to organize the clues and remember essential information.

Figure 6.3: The equipment used in the preliminary study, conducted to identify necessary features and the approximate completion time, is seen in this image. The cut-out clues could be moved around, notes (green) and labels (red) could be made, and specific information on the clues could be highlighted.

All three participants spent at least 10 minutes to read through all of the clues and did not find a solution within 20 minutes. Zagermann et al. [31] found that the average completion time was 911,08s with more distracting clues. Wozniak et al. [30] also included some distracting clues and estimated that the assignment would take 25 minutes to complete. The maximum completion time for this user study was set at 30 minutes based on the findings from the preliminary study and the information from the two studies mentioned above, additionally keeping in mind that the Hololens 2 is uncomfortable to wear for long periods of time and could lead to participants abandoning the user task. Participants could re-read the task both on the tablet (through the menu) and in real life while investigating the murder case (as a paper laying on both tables).

6.2.5 Data Gathering

During the study the participants were recording from two cameras set up in opposite corners of the room. One of the cameras had a microphone built in to record any comments or opinions from the participants. Every interaction on the tablet (clicking a button, adding content, etc.) as well as in Augmented Reality (deleting content) was also logged in separate files for further analysis. While the participants were investigating the murder mystery, the user position as well as the position and rotation of the content in Augmented Reality were logged independently, allowing for a full reconstruction of the sequence of events and visual representation of the interaction. The logging was done with a library developed by the University of Constance's Human-Interaction[2]and assessed with a python script. At the end of a user study a interview was performed to gain additional information and insight in the user's workflow and placement.

The data presented in Section 6.3 were acquired by watching the participants work on the user task and asking additional questions during the interview. A python file was used to rebuild the logged content in Augmented Reality as well as the participants' position. This visual representation, as well as photographs of the final representation captured with the Hololens, enabled for a reconstruction of the content placement and extensive analysis. The user's thoughts and workflow could be captured in the form of notes thanks to the thinking out loud method and recordings.

6.3 Results

This section describes the qualitative and quantitative results from the user study with regard to the research objectives.

6.3.1 RO1: Spatial Arrangement and placement of Content in Augmented Reality

The location of virtual material in Augmented reality will be discussed in greater depth in this section. Different layout patterns will be discussed, as well as thorough information on placement strategies observed during the user study.

[2]https://gitlab.inf.uni-konstanz.de/ag-hci/research/hci-evaluation-pipeline/hciep-unity-client (22.05.22)

Layout patterns

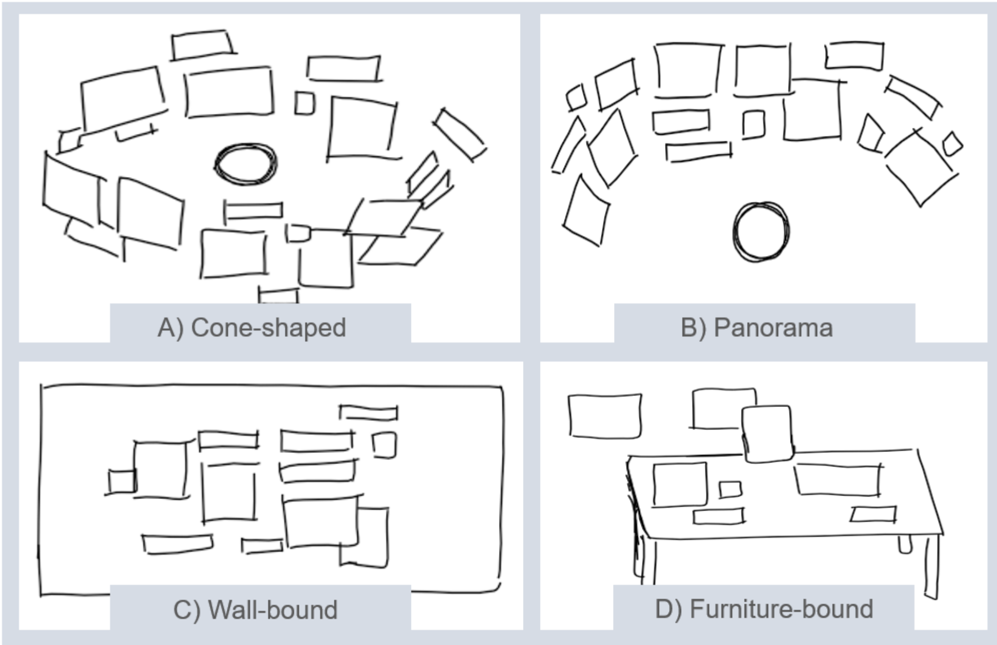

Figure 6.4: Sketches of the four layout patterns identified during the user study: Cone-shaped (A), Panorama (B), Wall-bound (C), Furniture-bound (D)

The final layout of the content was visualized and analyzed based on participant observations, photographs, and a visualization script. There are four distinct layout patterns that can be identified:

1. **Cone-shaped**:Participants created a cone of content around them and used depth to place content in the foreground or background (P2,P3,P8). As sketched in Figure 6.4 A and as example representation in Figure 6.6.
2. **Panorama**: The content was laid out as a horizontal strip with inward curves on both ends (P1,P5,P13). As sketched in Figure 6.4 B and as example representation in Figure 6.7.
3. **Wall-bound**: The information was placed using the walls as a guideline (P4,P10,P11). As sketched in Figure 6.4 C and as example representation in Figure 6.5.
4. **Furniture-bound**: The horizontal surfaces of furniture were used to place virtual content, just like physical objects (P6). As sketched in Figure 6.4 D and as example representation in Figure 6.8.

Because the content was placed in the centre of the room without any precise orientation, the remaining content placements (P9,P12) could not be allocated to any specific pattern.

Figure 6.5: Two photographs taken of two examples of the wall-bound layout pattern (P4,P10)

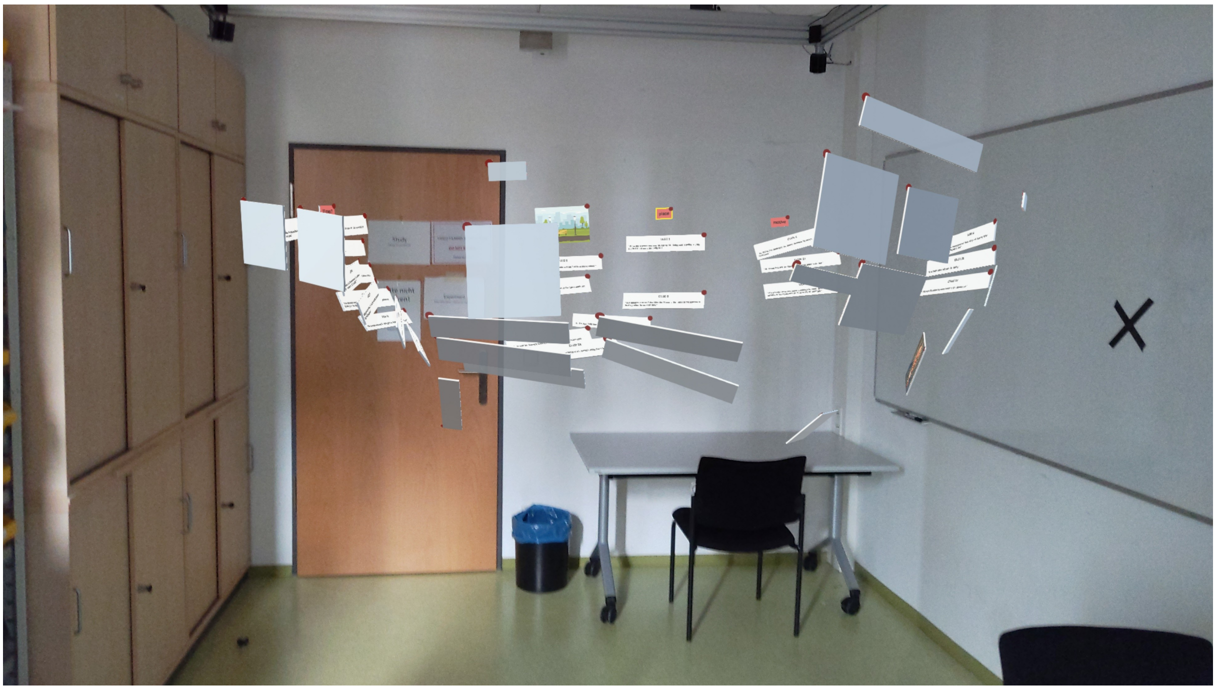

Figure 6.6: Photograph taken of an example of the cone-shaped layout pattern (P8).

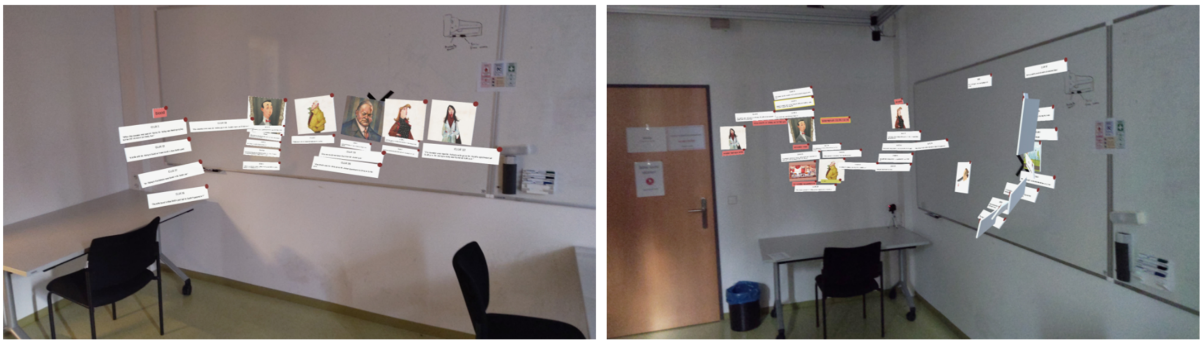

Figure 6.7: Two photographs taken of two examples of the panorama layout pattern (P1,P5).

Figure 6.8: Photograph taken of an example of the furniture-bound layout pattern (P6).

Placement strategies

The work types indicated in section 6.3.2 determined the height of the positioned content. Content was placed directly in front of the participants at chest height and within reach if they were standing, allowing for immediate close interaction (P1,P11). However, if the participant was sitting, the content was placed at head height so that it could be seen without having to stand up (P2).

Some participants used the content placement to construct an overview (P2,P3,P5) around them, allowing them to stand back and observe everything at once. Others chose to organize the content in one location so that it is always visible (P10,P11). One participant even stated that due to her ADHD, she needs to observe everything relevant during her sensemaking process or she will forget everything (P11). Content was moved to the foreground from the background to emphasize the relevance of specific pieces of information, and the size was increased to make it stand out (P2,P3). Content was positioned not just where it could be viewed immediately, but also outside of the field of view. Content that was not considered significant during the current working phase was placed in a "special spot" away from the participants' view, such as the floor (P6,P10,P13).

To organize the data, various types of data arrangements were established. Three individuals made a separate timeline to keep track of occurrences associated with a timestamp, and one described arranging the clues in a mind map to rapidly re-find relevant information. Because everyone had to submit their solutions at the end of the working session, three people decided to make a solution area out of notes and labels (P2,P4,P8).

Four participants made use of physical objects. The whiteboard was used to display information in the same way that a real whiteboard would (P6,P8), and one participant decided to utilize it for his organization since it reminded him of actual detective work (P10). The table was used as a storage space where one of the participants chose to place content such as tangible paper pieces (P6). Virtual content, as well as physical objects, were placed in a semantic context. Images were utilized to display information directly. For example, the knife image was reduced in size and placed in front of the yard image to indicate that it was discovered in the yard, and the image of the elevator man was given a bottle to place near his mouth to indicate that he was drinking alcohol (P3,P10). The room's limitations were also employed to arrange content. Participants utilized the walls as a guide (P3,P11) and expanded from there if there was no more room available (P6).

Participants formed several groups while making sense of and arranging the offered content. The majority of participants choose to organize their information by person (P1,P2,P3,P5). Participants frequently created labels for the participants' names and placed the appropriate image and information next to it. Another option was to organize the content using the study task's questions (P6-P8,P12). Participants constructed a solution area, in which the clues and images are placed exactly next to the corresponding question as an answer. To make sense of the time relations, three participants elected to order the clues in the different groups chronologically (P5,P10,P11), while other three preferred to create their own timeline (P2,P4,P8).

Multiple participants stated that the developed representation was not changed to seem pleasant or organized because they did not have enough time owing to the time constraint (P6,P9,P13). For the presenting phase, however, the representation was built out so that the majority of participants knew where to find which information. Only one person was unable to locate specific pieces of knowledge and presented the answers in a confused manner (P1).

Another factor that influences content arrangement is a lack of space to lay out all of the content (P6), as well as the size of the room. If the room had been larger, the participant stated that he would have arranged the content differently (all next to each other like a strip of content) (P8).

6.3.2 RO2: Workflow

All of the participants expect three, decided to go through the archive chronologically (P1-P8,P10,P12). The others began with one sort of content (pictures or text clues), then switched between the two when they added what they were looking for to Augmented Reality. One participant, for example, read a hint in which Miss Smith was mentioned. He wondered if a picture of Miss Smith existed in the archive after adding it to Augmented Reality and went on a search for it to add it next to the clue.

Notes and labels

During the study task, not all participants used the labels and notes. Three individuals (P1,P10,P12) did not use both, and one did not use the labels but made notes instead (P9). The other participants primarily utilized labels to organize their thoughts and divide them into groups. The study task's questions were added as labels to establish a sort of solution area (P2,P4,P8), and labels to keep track of the names linked with the images were also frequently made (P3,P5,P7,P11). Due to their red hue, which he linked with important information, one participant used the labels to mark important features (P9). On the other hand, notes were mostly used to keep track of thought processes (P3,P7,P9,P11) or assumptions made during the sensemaking process (P8,P9). One participant primarily used the notes to provide a summary beneath each group he made so that he could quickly access the solutions if needed (P9). The labels and notes were not always used differently. Three participants utilized them for the same purpose and just distinguished them by their color differences (P4,P5,P8).

Filters

Two participants did not use the filters since they did not think it was necessary because the archive did not have much content (P4,P10). The filters were mostly used by the other participants to filter out the content they had already added to Augmented Reality. This allowed them to rapidly reread the hints they had sorted out and gain a sense of their current status (P2,P3,P6,P9,P12). The photographs were also filtered out using the filters. Three participants disliked dealing with images and believed they are unnecessary, therefore they chose to focus on the text clues after adding all of the essential photos to Augmented Reality (P9,P11,P12).

Images

Three participants utilized the images to provide a visual representation of the clues. Images that corresponded to the clues were found in the archive and added to the Augmented Reality groups (P5,P6,P7). Participants decided to begin by working with the images and then match the clues accordingly during the first sensemaking phase (P3,P2,P8,P11). As a result, various groups centered on the images were formed. After trying to zoom into the images for possible hidden information, two participants decided not to utilize them (P9,P12).

Hand Interactions

Participants employed various hand interactions supplied by the system while interacting with Augmented Reality content. The far interaction was used by around half of the participants (P1,P2,P6,P10), whereas the near interaction was used by the other half (P3,P4,P7,P8,P11). The majority of participants (P3,P4,P7-P9,P11) placed the tablet on a piece of furniture and used both hands to resize and rotate the content, whereas two people did not use them at all (P5,P10).

Other

Even though the physical environment could be observed at any time through the head-mounted display, three participants were unaware of their surroundings. They pumped into chairs and against the wall or whiteboard when portioning content near it while working with the content. This could be because they were too preoccupied with their sensemaking to notice their surroundings (P4,P5,P11). Another person engaged with the virtual objects as though they were real (P9). While rearranging the content, the participant made sure that his hands did not penetrate other content, as if they were solid.

Work Types

The participants demonstrated several ways of engaging with the tablet and Hololens 2 while using the available furniture. There are four different work types that can be distinguished:

1. **Standing** (P3,P5,P7-P11,P13): The participants stand for the duration of the study activity and either work with one hand interaction because the tablet is always in one of their hands, or alternate between one and two hand interaction by placing the tablet on a surface (table, chair) to use both hands.

2. **Sitting** (P2): The participant mostly employ far interaction to move content around while seated in the centre of their representation. Content is frequently adjusted using two-handed interactions. The tablet is easily placed on the lap to allow both hands to work concurrently.

3. **Hybrid** (P1,P2,P12): Participants alternate between sitting and standing positions. Participants tend to sit down and take their time when searching through the archive and reading clues. Two-handed interactions are utilized to change and position specific content in Augmented Reality, which leads to them standing up and directly manipulating the content with near interaction. A participant, for example, placed his tablet on the chair while resizing a clue. In a loop, some players alternated between holding the tablet in their hands to spawn a new clue, placing the tablet down to resize it with two hands, and then holding the tablet in their hands to spawn something new.

4. **Spawn point** (P4,P6): The participants utilized the tablet as a spawn point by placing it on a table. The content was viewed while standing up on the table and spawned in front of them. The spawned content was primarily positioned around them using two hand interactions.

Interaction Types

Furthermore, two separate interactions between the tablet and the content in Augmented Reality can be distinguished:

1. **Add everything to Augmented Reality** (P2-P5,P8,P10): The participants used the archive to browse through all of the accessible content, putting it all into Augmented Reality and placing it. The text was then reread and rearranged in Augmented Reality as needed. Content which was deemed irrelevant was positioned in a "spacial place" to review in later stages. The tablet was just used to check if everything had been added without missing a piece of information following the adding process. In Figure 6.9 the logged data from four different participants are summarized and analysed. Each rectangle displays the amount of times a specific content from the archive to Augmented Reality (left upper area) including an amount of images and clues added in total, the amount of content deleted distinguishing between images and clues (left lower area) and the amount of times a specific content was viewed (clicked on) through the archive (right area). The interaction type described can be related to the amount of content added to Augmented Reality and the amount of content viewed in the archive. The participants (P2,P3,P8,P10), as shown in Figure 6.9, added the majority of the content to Augmented Reality, some of it multiple times. The images were generally left out since the participants didn't think they were crucial to include in their representation (apartments, drugs, elevator). The participants viewed the different content in the archive at least once (except for images because they could already been identified through their icons in the archive) before adding it, but they did not utilize the tablet to view it again as much as the second interaction

group (Figure 6.10). The overall amount of content added and content viewed on the tablet are nearly the same, indicating that participants read the clues once in the archive and in the later stages of their sensemaking process proceeded to read and work with them primarily in Augmented Reality. This behavior was also evidenced by the recordings.

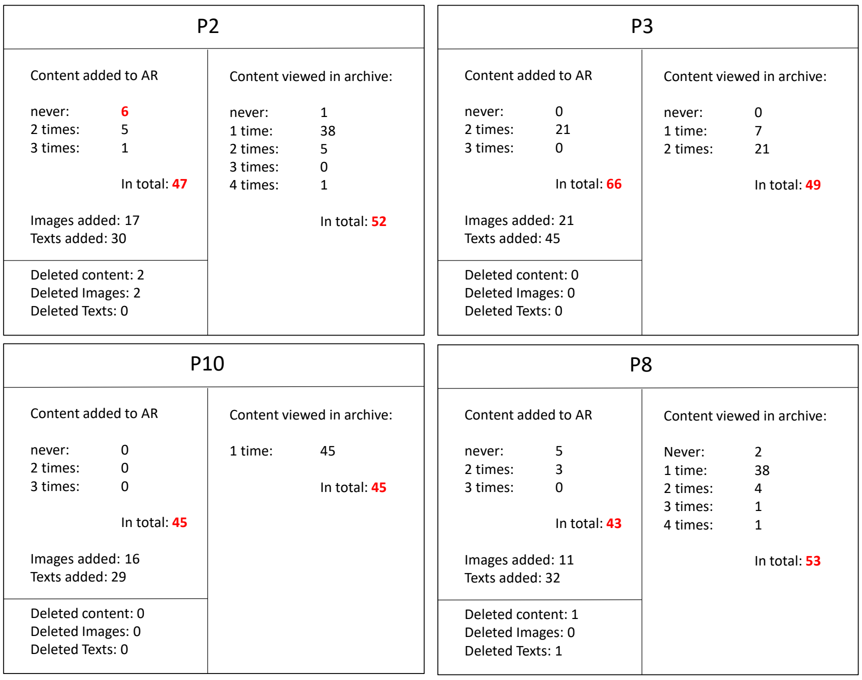

Figure 6.9: Example of data gathered during the user study from four different participants (P2,P3,P8,P10) adding everything to Augmented Reality, including the amount of content added to Augmented Reality, the amount of content removed from Augmented Reality and the amount of individual content viewed in the archive.

2. **Filter through Augmented Reality** (P1,P6,P9,P11-P13): The participants filtered content from the archive using Augmented Reality. Only the most pertinent clues were added and placed in the room. The tablet was then used to reread the non-added hints in order to see if they were still relevant later in the process. The hand-held device hereby contains the filtered irrelevant content, which will possibly be revised in later phases, and the head-mounted display the relevant information with which the participants create a visual representation to make sense of it. Figure 6.10 (displays the same logged data as described in the previous part) shows the relationship between the amount of content added and the amount of content viewed. The participants do not add every piece of content from the archive to Augmented Reality, and they rarely add the same piece of content twice. The majority of the work is done on the tablet, thus the overall amount of content viewed in the archive is reduced. This group utilized the tablet to review clues, compare them to those added to Augmented Reality, and search for keywords (P9). The logged data also reveals that participants are more likely than the initial interaction group to examine content in the archives multiple times (up to ten times).

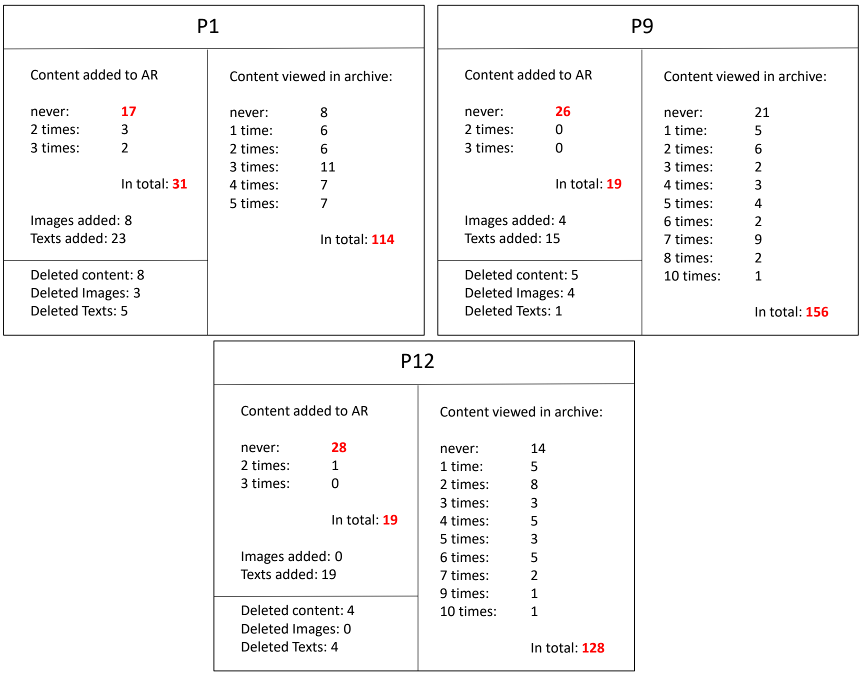

Figure 6.10: Example of data gathered during the user study from four different participants (P1,P9,P12) filtering the content with the help of Augmented Reality, including the amount of content added to Augmented Reality, the amount of content removed from Augmented Reality and the amount of individual content viewed in the archive.

Sensemaking Phases

All participant's sensemaking process except one (P12) can be separated into two main phases:

1. **Read and filter content**: Participants begin by reading all of the content available in the archive during the first phase. The content is filtered with the tablet and Hololens 2 (essential content in Augmented Reality, irrelevant content is not included) or by placing and arranging the content in Augmented Reality after it is added, depending on the interaction types indicated above. To acquire an overview, the first groups and representations are created in Augmented Reality.

2. **Connect information**: In the second phase, participants begin to reread the clues and reorganize the groupings and representations generated in the previous phase, depending on the type of interaction, either on the tablet or in Augmented Reality. The participants strive to make connections and figure out the answers to the questions here. Final adjustments are made to create the final representation used for the presentation of the results.

6.3.3 RO3: User Experience

The prototype received generally positive feedback. "Fun" and "exiting" were the participants' words to characterize their experience (P1,P7,P9,P10,P11). The overall system was also thought to be simple to use and integrate into daily workflows (P1,P2,P8,P12).

"I felt like a real scifi detective working on a case. It was a fun experience!" - P10

User Experience Questionnaire

To acquire an overview of the system's usability, the User Experience Questionnaire was used (see Appendix). Figure 6.11 displays the results in relation to the systems attractiveness, stimulation, novelty, perspicuity, efficiency and dependability. Attractiveness, stimulation, and novelty were all rated as excellent in the study. This could be owing to Augmented Reality's novelty. New technologies are frequently regarded as engaging and exciting to use. Perspicuity and dependability were also given high marks. This could indicate that the system had no observable issues with the tablet and Hololens 2 interaction. The transition from tablet to Augmented Reality went successfully, with no issues reported by participants. The high perspicuity score could be regarded as the system being easy to comprehend and utilize, emphasizing the participant's statements. The participants' poor efficiency score in comparison to the other characteristics could be explained by issues with Augmented Reality interaction. Participants grew annoyed since grabbing content did not always function. Only being able to move one piece of material at a time could possibly explain the poor score, as moving larger groupings takes less time and is more efficient.

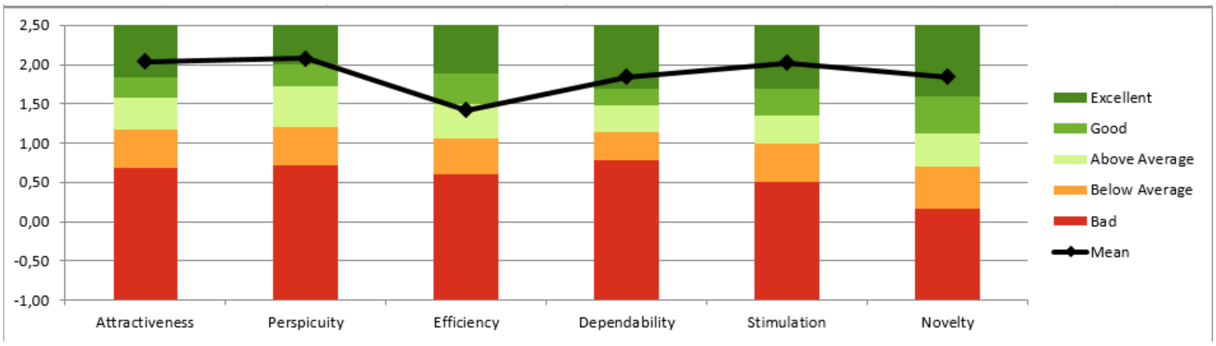

Figure 6.11: Result from the UEQ data analasis tool[23]

Habituation phase

Despite the fact that the system was described as simple to use, all of the participants except three which have already worked with the Hololens before (P8,P11,P12), took some time to become familiar with all of the features and interactions. Some users stated that the interaction in Augmented Reality was foreign at first, but that learning the proper interactions and managing the interaction between the tablet and the Hololens 2 was simple and quick (P1,P4,P9,P10).

"I had no problems with the system. At first it was a bit weird to use but then it was easy to get used to and interacting with the content got faster and better with time" - P9

This habituation period can be explained by the fact that the majority of participants have never used a hybrid interface that incorporates a new technology like the Hololens 2 before. This may cause them to be firstly overwhelmed by its features and aesthetic presentation. Even if everyone went through an initial training phase to reduce the effects of getting to know the system during the user task, knowing how to properly interact with the information in Augmented Reality requires time that the training period cannot fully compensate for. Another explanation could be that some users were overwhelmed by the amount of information and images provided to them in the archive at the start of the user study, as well as feeling rushed owing to the time constraint (P1,P5,P8,P9). Participants may become upset as a result, and it may take them longer to become used to working with the prototype.

"Wow those are a lot of clues! Do I have the time for that?" - P1

User Interface

The user interface was thought to be very clear and simple to use (P1,P6,P11). The participants had no trouble navigating the many clues and adding content to Augmented Reality. Switching between clues could be done fast, allowing participants to search clues for specific terms (P9). One participant didn't realize immediately that all of the content in the archive could be transferred to Augmented Reality, so she took notes to remember what was written in the clues, but she had no trouble working with them later (P11). Several participants mistook the filter label for a button and anticipated a drop-down menu with the available filters to appear (P2,P4,P8). They realized the filter was underneath after continuously pressing on the filter label and receiving no reaction from the interface. It was mentioned that because using notes and labels on a tablet keyboard was time consuming and inconvenient, they were not used (P5,P7).

**"The labels and notes were tedious to use because of the keyboard,
it would have been easier to write on the tablet with a pen" - P7**

Four out of all the participants decided to not use the filters (P1,P4,P5,P10). Two of them added everything to Augmented Reality and then stopped using the tablet, while the others stated that there wasn't much content to work with and that the filters were unnecessary. The participants who used the filters tried each one at least once, with the "not added" and "added" filters being the most popular, as they wanted to see what they had already placed in Augmented Reality and possibly reread certain pieces of information.

Two participants did not use the filters or notes provided (P10,P12). They stated that the information on the clues was brief enough that they did not require additional notes to retain information. The majority of the labels and notes were created through the text view and archive (P1,P3,P5,P8,P9,P13). This could be because the participants wanted to immediately add their own input after reading something they deemed interesting and wanted to remember. Another explanation could be that several people indicated using the labels as a name tag for the images in the archive (P3,P5,P7,P11), since the image names are only shown in the archive, not in the image view. Only one participant used the menu in the tablet application to add labels/notes and review the study task while working on the murder mystery activity (P2). The rest only used the archive to swiftly move between clues and label/note creation and did not navigate back to the menu.

Interaction

While working with the prototype, various challenges arose when dealing with Augmented Reality content. Grabbing the content to reorder it did not always work immediately, which frustrated three participants (P3,P4,P10).

The labels, in particular, were said to be too small to grasp comfortably (P8). One participant also struggled to determine the appropriate depth to engage with content utilizing near interaction (P13).

"Grabbing content did not work all the time, but the highlighting helped to figure out when a content was grabbable" - P3

A participant also remarked that getting the appropriate hand placement for the Hololens 2 to identify was difficult (P6). However, after some practice, the participant became accustomed to the hand gestures and learned how to position them so that the system recognized his intents immediately. Another element of the hand recognition was that four participants complained about it being too sensitive. The Hololens 2 recognized hand gestures associated to far interaction while holding the tablet and moved previously placed content without the user's permission (P5,P8,P9). With one participant (P1), the Hololens 2 menu appeared many times, which could be related to the manner the tablet was handled in one hand and this could have been mistaken as the menu hand gesture provided by the Hololens system.

"While i was holding the tablet it got mistaken with a hand gesture which moved content without me wanting to. This was annoying since i had to reposition everything again" - P5

Working with the iPad made it difficult to interact with the Augmented Reality content. Participants had to lay the tablet down if they wished to utilize the two-handed interaction to scale or rotate a specific piece of content (P7,P8,P13). For this reason, two participants elected not to use the two-handed interaction because they found it uncomfortable (P8,P13).

"The tablet was inconvenient to use since you had to put it down to rotate content, that is why i did not use this feature" - P8

Eleven out of thirteen participants liked having the content appear in Augmented Reality. Only two individuals reported problems with the spawn distance and had to take a step back to engage with it after spawning (P5,P10). A bug was discovered in which content was spawned in a wall and participants were unable to interact with it (P5,P11).

Positioning

Eight out of thirteen participants were favourably surprised by the potential utilization of space around them when it came to the location of material in Augmented Reality (P3,P4,P6-P8,P10,P11,P13). The ability to freely generate representations in the room was seen as beneficial to their work process (P3,P7,P10,P11,P13). The ability to flexibly position content in Augmented Reality, as well as the ability to use the depth of the surroundings, helped two participants (P2,P10) separate and group the information. One participant found that positioning content in different depths to make it stand out or adding content without having to change the entire representation is beneficial (P10).

"If you did not have the space where you wanted to position a certain clue, you did not have to move everything, you could just place it in front of it" - P10

Two participants found it useful to be able to build larger representations and see whatever they created at any time without having to look at the tablet again because they had the room available and could freely pick where to arrange the content (P5,P11,P13). The ability to develop a mind map in the room was also cited as a beneficial factor in identifying relevant content (P6).

> **"It was helpful to have content in AR, it let's you organize your thought process and directly see everything in front of you as you work" - P6**

Because the content could be placed directly in the room, two participants felt as though the virtual content had totally integrated into the real world and blended in nicely with the real-world objects (P2,P5). The environment was used by eleven participants to directly integrate it to the user task. Because the whiteboard was associated with detective work, it was used by one participant as a genuine whiteboard (P10).

> **"I used the whiteboard because they use it in detective movies and i wanted to feel like a real detective on a case" - P10**

One participant did not take advantage of the available space and stated that he did not need to develop an Augmented Reality representation to solve the case because he had already created a mind map in his head (P12). Another participant remarked that she would not utilize the prototype in a real-world situation because it takes too long to organize the various content in Augmented Reality without the assistance of positioning guidelines provided by the system (P1).

> **"I would not use it in real life. It's practical but it takes too much time to organize everything and adjust it. Every content needs to be rotated and moved on its own" - P1**

Other

It was mentioned that the Hololens 2's field of view is very limited, making it difficult to see the content when scaled up, and that it was essential to take a step back to see all of the content positioned in Augmented Reality as an overview (P2,P4). Another participant, on the other hand, stated that he had no visible limits due to his field of view and that he was too focused on the murder mystery task to perceive it (P6).

> **"The field of view was not an issue since i was so focused on the task itself that i did not notice it" - P6**

Two participants stated that the Hololens 2 was too huge and heavy (P1,P12), which caused one of them to experience headaches (P12). Another participant stated that the Hololens 2 was not too cumbersome or difficult to wear while doing the work and did not provide any distractions (P2). It was mentioned that the tablet was too large and heavy to use and was inconvenient. In this situation, a tiny smartphone would have been preferable (P8). The generated content was described as blurry and too large, making it difficult for two participants to read the clues in Augmented Reality (P4,P12). Two other participants found it beneficial to be able to read the clues in Augmented Reality rather than having to use the tablet again (P8,P12).

> **"I liked that you were able to add your own input with notes and labels" - P11**

One participant stated that he does not believe there is a difference between Virtual and Augmented Reality in this activity since he was too concentrated on finishing the assignment to notice his surroundings (P5). Three other participants reported about not being aware of their surroundings. They forgot the whiteboard was a wall and bumped against it while engaging, or they didn't notice the objects around them (like the chair) (P4,P5,P11). The task was thought to be enjoyable to work on, but difficult to complete owing of the time constraint (P9). Two people only had just enough time to solve the case and come to a conclusion (P9,P2). Despite the fact that the images were introduced to provide visual material to aid the participants in their sensemaking process, two individuals did not find the images beneficial and found them perplexing. They zoomed into the photographs to hunt for details because they thought the images might hold hidden information (P9,P12). However, once this notion was abandoned, the images were readily disregarded using the filter function and did not cause any further issues. The two devices were another popular approach for participants to filter the content. The content on the tablet was deemed unimportant, whereas the content added to Augmented Reality was deemed necessary. Two participants stated that this kind of filtering benefited their problem-solving process (P11,P12).

The ability to freely roam around the room and sit down at any time was a feature that three participants found valuable in allowing them to immerse themselves more fully in a real-life scenario (P1,P2,P12). On participant did not make use of the available space and stated that laying paper clues on a table would have made no difference to him (P12). This could be because this participant prefers to tackle problems mentally rather than through a visual depiction.

"I liked that i was able to freely move around in the room and also sit down at any time" - P2

Another useful feature was the ability to add content to Augmented Reality. Participants commented on how convenient it was to have content right in front of them without having to look at the tablet (P1,P11). In Augmented Reality, the content was said to be very apparent and readable (P8).

"I liked that i could add content from the tablet to AR, so that i don't have to look at the tablet all the time" - P11

Suggestions

Participants suggested several improvements to the prototype as well as features that would have benefited them in their problem-solving process. While reorganizing the presentation created, a multi-selection tool for the content in Augmented Reality was noted as being useful (P1,P8). Because the current system only allows one piece of content to be moved at a time, two participants decided not to change too much of their first depiction because it would take too long. In Augmented Reality, arrows or string were suggested to connect the various clues (P1,P5,P6,P7,P10). These participants agreed that seeing the links between the clues and putting everything into context would be beneficial.

"Read connective strings between the clues would have been fun to use and made me feel even more like a real detective" - P7

One participant indicated that a color coding system would have helped them distinguish between important and unimportant items (P6). Depending on the context and topic, this approach might potentially be utilized to create groups with different colors. A group with a suitable name and color might be formed. Every piece of content may then be added and removed as desired to the various categories, and aligned directly to make the user's work easier (P7,P8). The groups might also be relocated as a whole, eliminating the need for the user to move each piece of content individually as in the current system.

A word search tool was also requested, in which the user could enter a word and have the clues that include it highlighted in Augmented Reality (P13). This would be useful for finding specific information included in Augmented Reality without having to reread every single clue and being able to see the links between the clues immediately if, for example, a name is referenced in numerous clues at the same time.

6.4 Discussion

This section examines the findings in regard to the research objectives, theoretical foundations, and related work addressed in the preceding chapters.

6.4.1 RO1: Spatial Arrangement of Content and placement in Augmented Reality

Users appreciated being able to place content all around them in Augmented Reality and take advantage of the space available. The ability to build sophisticated representations in space aided them in completing the work and led to alternative arrangements.

How is content spatially arranged and laid out in Augmented Reality?

Four alternative layout patterns were discovered in the final layout developed by the participants: cone-shaped, panorama, wall-bound, and furniture-bound (Section 6.3.1). Compared to the layout patterns identified by Luo et al. in their initial paper [10] the following conclusions can be drawn:

Figure 6.12: Results of the comparison of this thesis' identified layout pattern with the ones identified by Luo et al. in their first paper. The panorama pattern can be compared to the panoramic strip and semi-cylindrical pattern (left), the cone-shaped pattern with the panoramic strip (middle) and the wall-bound and furniture-bound pattern with the furniture-based pattern (right).

The panorama pattern identified can be linked to the panoramic strip and semi-cylindrical pattern mentioned (Figure 6.12 left). The users in the Luo et al. user study used more room to build this strip, resulting in the ends of the strip practically touching, but the participants in this user study arrange the content in a more dense region. As a result, the panorama pattern resembles a hybrid of the panoramic strip and the semi-cylindrical pattern.

The panoramic strip can also be linked to the cone-shaped pattern (Figure 6.12 middle). The strip does not exactly depict this pattern because it does not totally surround the user, but it does follow the similar contour. When compared to the panoramic strip given by Luo et al., where content is aligned in a strip form, users in this thesis' study tend to develop more inwards the center of the cone representation while employing depth.

The furniture-based distribution can be related to both the wall-bound and furniture-bound patterns (Figure 6.12 right). Walls and whiteboards, which are part of the wall-bound pattern proposed in this thesis, are included in Luo et al.'s definition of furniture. The furniture-bound pattern explains the content arrangement in a broader view, where the content is distributed across the space in separate clusters. The two patterns discussed in this thesis do not consist of content distributed around the space, but rather are more compact.

When comparing the four patterns to the further identified pattern in Luo et al.'s latest paper [9], different comparisons can be made:

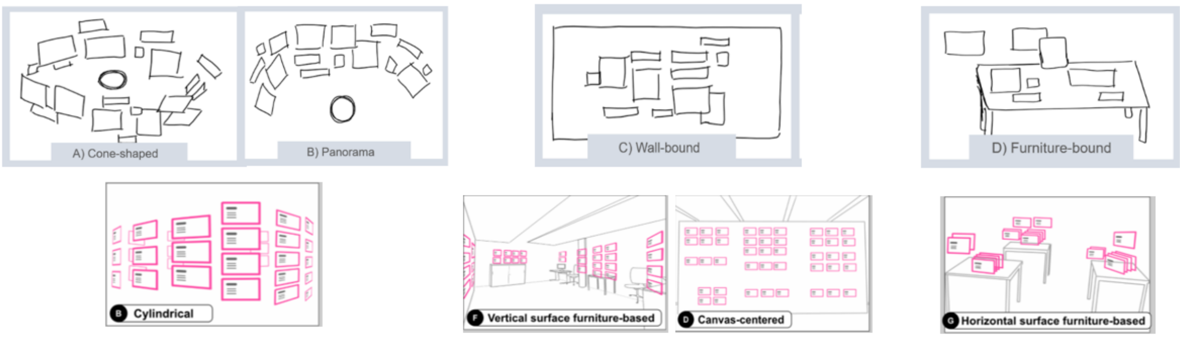

Figure 6.13: Results of the comparison of this thesis' identified layout pattern with the ones identified by Luo et al. in their second work. The cone-shaped and panorama pattern can be compared to the cylindrical pattern (left), the wall-bound pattern to the vertical srufaces furniture-based and canvas-centered patterns (middle) and the furniture-bound pattern to the horizontal surfaces furniture-based pattern (right).

The panoramic strip and semi-cylindrical pattern discussed in their earlier study are included in the cylindrical pattern mentioned in this paper. As a result, both the cone-shaped and panorama patterns, as explained before, can be compared to it.

There is no difference in the wall-based pattern between furniture that is mounted on the walls, such as whiteboards, and plain walls. As a result, both the vertical surface furniture pattern and the canvas-centered pattern would be suited. The walls and whiteboard were used as clustering guidelines in the wall-based pattern, just as they were in the canvas-centered arrangement.

Finally, because the participants in this thesis study generally employed the tables as anchor points for their content placement, the furniture-bound pattern would match the horizontal surface furniture based group indicated by Luo et al.

During the user study, no grid-like pattern was discovered. This could be related to the time constraint, as participants stated that if they didn't have it, they would take their time to position the content in a more attractive manner. Luo et al.'s three other furniture-centered patterns (furniture-anchored cylindrical, furniture-aligned cylindrical, and omni-furniture-based) were similarly unidentified. This could be due to the furnishings and room settings chosen. Different room settings were used in the study by Luo et al., with more and diverse furniture. More furniture, according to their findings, leads to more physical surrounds being employed for pattern development, which the setting for this thesis' investigation did not provide.

6.4.2 RO2: Workflow

How are the tablet and Hololens 2 being used to complete the study task?

The expected outcome was that the participants used the tablet primarily as an information source in the initial stage of the study, with the Hololens assisting them in organizing and making sense of the data in the last stage of the sensemaking process. But the usage of the tablet at different stages of the sensemaking process, as well as the frequency with which it was used, varied depending on the interaction types outlined in section 6.3.2. Users who desired to add everything to Augmented Reality did not utilize the tablet as often as users who choose to filter content through Augmented Reality.

The notes and labels were used either as a help for the group creation or to retain important thought processes. Whereas the filters served the users as a way of structuring their work process and help them navigate through the big data set in the archive. These scenarios were expected, although the utilization of these features was presumed to be greater.

The study's four main work types (section 6.3.2) revealed that while working with virtual information, some users observe and interact with their actual surroundings like in a real work scenario. This reinforces Augmented Reality's importance in future sensemaking environments, which can be further investigated in future research.

How can the workflow be mapped to the sensemaking process?

Using the model suggested by Russel et al. [17] the following activities and work processes can be mapped to their representation of the sensemaking process:

Participants came up with a preliminary notion for how to organize the content while looking through the archive. The first group formation notion was conceived in Augmented Reality, and a first work approach was implemented. This can be compared to the representation search process. Following the creation of these basic groupings, the rest of the archive's content is evaluated before selecting whether or not to include it in the current interesting representation. Depending on the type of interaction, only relevant information is categorized into groups, or all content is sorted into groups (additional group for irrelevant content). The encodons are thus the many groupings formed and the content arranged within them. When new content is added to the overall representation, new groups and sub-groups are produced while chronologically processing the archive's content. The residue is the content that does not fit or is not required to solve the case. Depending on the interaction type, this residue can be content just present on the tablet (not added to Augmented reality) or content placed in the "irrelevant" group. The shift representation process can be thought of as the process of altering the groups. Consume encodons, the final procedure, can be assigned to the following activities. The formed groups are utilized to complete the task-specific operation, which in this case is to solve the murder case mystery. These answers can be changed while working on the assignment, resulting in another pass through the learning loop complex until the participants choose to deliver their answers or the time runs out.

Furthermore, the work of Pirolli et al. [13] can be utilized as a more thorough foundation for understanding the participants' sensemaking process. To begin with, the various data flow types indicated in their research can also be found in the user study results:

The content offered to users in the archive on the tablet is an example of external data sources. It consists of images and text files in the study. The participants then elected to filter the content in order to gain a better overview of the relevant information. This stage is dependent on the interaction type (section 6.3.2) and corresponds to the model's shoebox definition. The evidence file was proposed as the next data flow type, in which bits of relevant information are retrieved from the now pre-filtered content. Some participants in this thesis' user study followed this pattern by extracting the most significant information into notes. However, because the clues did not consist of a lengthy text with a lot of diverse information and could be directly integrated to Augmented Reality, most of them did not have the need to extract pieces of information. To solve the murder mystery assignment, the clues and any additional input given through notes were organized into several schemas in Augmented Reality. The schemas can be compared to the various groups that were formed to organize the content. Participants were divided into groups that assisted them in swiftly finding specific bits of information, connecting the clues, and solving the case. The groupings then lead to first responses, which can be supported by additional information (For this study clues). The hypotheses data flow type is comparable for this phase. Some participants went even further, producing solution spaces or a summary beneath the individual groups with possible responses, demonstrating a clearer usage of a hypothesis. The content (arguments) supporting the answers written on notes or labels are the clues and images in the groups. Finally, the type of presentation data flow can be identified. Participants had the opportunity to make final revisions to their representation during the last five minutes of the user task, which was then used as a form of presentation to express their answers to the study advisor.

The results pointed to two distinct sensemaking phases, as described in section 6.3.2: "read and filter content" and "connect information." These two phases are very similar to Pirolli et al.'s main loops. The "read and filter content" phase can be described as the Foraging loop, while the "link information" phase can be described as the Sensemaking loop. In Luo et al.'s recent study [9] they delved into greater detail on the many parts of the sensemaking process and identified four stages that can also be linked to Pirolli et alt.'s main loops. These four stages are quite similar to the data flow types that have already been explained and compared to the study outcomes, thus they will not be evaluated or compared again. However, in their first planning phase, Luo et al. discovered two different approaches. The overview approach, in which users evaluate all data before grouping it, and the iterative approach, in which users prefer to form categories based on the first items they see and then add to them. In this thesis, the overview technique was not identified. While analyzing the data, all of the participants adopted an iterative approach. The archive was searched through using various methodologies, but every content contributed to Augmented Reality was immediately sorted and clustered in space. This could be due to the hybrid prototype that was used. The content provided to the participants in Luo et al.'s study was evenly dispersed throughout the room and so was already visible to the participants in Augmented Reality. The content produced by this thesis' study, on the other hand, was only available through the tablet's archive and had to be manually incorporated to Augmented Reality.

The many bottom-up and top-down processes outlined by Luo et al. can also be found throughout the research for this thesis. First, we'll talk about the bottom-up processes: The archive was used to complete the search and filter process, in which participants looked for relevant information or more clues to support their theories, and filtering was differently done depending on the various interaction types. Using text-based clues, notes, and labels, it was also possible to read and extract chunks of information. Some participants extracted the information using these notes or labels, while others proffered to directly add the clues to Augmented Reality and use them as extracted data. The representation of the data in a schema was mostly done in Augmented Reality. Only one person stated that they had created a mental representation. Building a case and telling a story have already been examined as part of the comparison with hypotheses and presentation data flow type, and will not be discussed again. The top-down processes will be detailed next: Participants looked at the content that had already been grouped when constructing the Augmented Reality representation and updated it if it no longer fit the changing depiction. Participants re-read the clues in the archive or Augmented Reality, depending on the interaction type, to ensure no information was missed in the later stages of the work process, or searched for additional evidence to back up their theories. These behaviors are all part of the re-evaluate, search for support, search for evidence, and search for information processes outlined by Luo et al. Participants took use of the given space to take a step back and assess their work. This allowed them to gain a comprehensive perspective and look for possible links between the various clusters, which is a relational search.

6.4.3 RO3: User Experience

The system was thought to be intriguing and enjoyable to use. Nonetheless, it took some time for participants to get used to using the Hololens 2. This could be because the head-mounted display is a novel technology that only half of the participants had used before. The user study was also limited to one sensemaking activity, which provides insufficient information on the system's usability in other scenarios. The study focused on the placement and movement of content in Augmented Reality, as well as the workflow utilizing a hybrid user interface.

Does the system aid the users in their tasks?

Five out of ten participants solved the task correctly and only three did not find right answers to more than one question. The majority of participants said the approach helped them organize their thoughts and obtain a better understanding of the murder case. The ability to display material anywhere in the room surrounding the user allowed them easily re-find certain information based on their location. The interface allowed participants to freely switch between the many clues and filter out content. The interface and system were praised for being simple and intuitive. The ability to add input in the form of notes and labels aided participants in solving the case and remembering essential information. The participants were able to reconstruct the story of the murder case while providing the answers to the study advisor during the presentation phase by being able to examine the representation made while working on the task. To quickly recover information in a certain context, a mind map or timeline was built.

Some issues arose, largely relating to the interaction with Augmented Reality content. Participants found it annoying and time consuming to individually put and adjust each piece of material because the system did not include a multi-selection tool or content guidelines. Because of this restriction, some participants elected not to move specific content, which may have affected their sensemaking process. Because hand gesture identification was unreliable, several participants became frustrated and stopped moving or altering specific content.

Overall, the method assisted most participants in organizing their thoughts and grouping their findings, allowing them to acquire a good picture of the case. Due to missing features, problems with the gesture recognition and the longer habituation phase, the participants took longer to solve the task or did not find the correct answers due to the time restriction.

Does the prototype support the sensemaking process?

The workflow was compared to other sensemaking models (Section 6.4.2), revealing that various sensemaking activities and processes can be recognized. As a result, it can be said that the prototype enables users to carry out the actions and activities that are required for a sensemaking activity. Furthermore, regardless of whether the solution was correct or incorrect, all of the participants found one, demonstrating that they were not completely clueless while working with the system. The method also benefited the participants in structuring their thoughts and organizing the larger data set presented, which are crucial components in making sense of unknown data, according to the user interview. Therefore it can be said that the system supports the sensemaking process in general, but it can also depend on the users way of interacting with it, since one participant favored making his own representation in his mind rather than using the system as aid.

6.5 Limitations

The user study that was previously presented has several limitations. First and foremost, the user task's time constraint influenced the user's positioning and workflow. This restriction could be reduced in the future to allow researchers to study virtual content interaction in a more realistic situation. The task does not represent all tasks that need sensemaking and brainstorming. More complicated tasks, using larger text files or a wider range of data formats (such as videos) may be used in future studies. As a result, the prototype features may need to be adjusted, and thus users may interact with it differently. In addition, especially in a work environment, the sensemaking process frequently involves numerous collaborators. Because this user study did not include interactions between several users, it is possible that some crucial steps and components of the sensemaking process were omitted. Another factor to consider is the impact of the room's size and environment. Participants stated that if the room had been sized differently, they would have put out the content in a slightly different ways. The way users put content in Augmented Reality is highly influenced by the furniture, according to Luo et al. [9]. In the future, the hybrid user interface prototype might be used to investigate different room sizes and furniture styles in order to learn more about the sensemaking process. Furthermore, because the system employed in the study is still a prototype, it has a number of hardware and software constraints. Some participants thought the Hololens was unpleasant and heavy to wear, and the tablet was too heavy and large. Both may have had an impact on the sensemaking process and user satisfaction. Due to the lack of a larger perspective, the field of view of the head-mounted display may have influenced how participants positioned the content in Augmented Reality. The Hololens' hand gesture recognition did not always perform as expected, causing some participants to become upset. The system also had a minor problem where material spawned in a wall could not be interacted with. Some of the prototype's features were missing some additional guidelines and helpful attributes that may be introduced in future work, as noted in section 6.6.

6.6 Future Work

Future work could include changing the prototype based on the participant's comments, as detailed in section 6.3.3. It might also be improved by combining the labels and notes and allowing a free color selection. It would be beneficial if the user's notes could be modified after they were added, allowing them to adapt to the users' changing theories. A copy and paste option incorporated directly into Augmented Reality, as well as the ability to open content on the tablet while seeing it in Augmented Reality, would make interaction with the content even faster. Users no longer have to search through the archive for the proper material and can engage with it instantly. Another option to improve the interaction between the tablet and the Hololens is to highlight material in Augmented Reality while it is open on the tablet. An off-screen visualization on the bottom of the head-mounted display might also be used to swiftly re-find certain material in Augmented Reality. Finally, a pencil interaction can be implemented, allowing users to draw on images and add handwritten comments to the clues. This would make extracting meaningful data much easier, as participants complained that working with the keyboard took too long and was too tedious. This also could be offset by employing a smaller device, such as a smartphone, for the hand-held device.

In terms of the user study, the impacts of different room and furniture settings on the sensemaking process and content placement when utilizing a hybrid user interface might be investigated, as well as the collaborative component. Hand-held gadgets of various sizes could potentially be used and examined in terms of workflow and sensemaking. To see if the interaction or work kinds indicated in section 6.3.2 would alter or remain the same. If a tablet or a larger gadget is to be utilized, the ability to attach it to the user's body with a belt could also modify how they interact with it.

Furthermore, the logging could be expanded to track the position of the hand-held device and the users' eye movement in order to assess the interaction and user behavior in greater detail.

7 Conclusion

The design and evaluation of a hybrid user interface prototype for individual sensemaking tasks are discussed in this work. It combines a head-mounted display with a hand-held device, with the tablet acting as a data source and the Hololens acting as a means of representing and making sense of the data. The use of an Augmented Reality device allowed the user to freely arrange and group virtual content, allowing complex representations to be created. The criteria for this prototype were derived from sensemaking foundations, literature research, and systems proposed in related work. A user study with thirteen people was undertaken as part of this thesis to investigate how users interact with the prototype and execute sensemaking activities with it. The task consisted of a murder mystery task that the participants were asked to solve using the prototype. Three research objectives with related research questions guided the study. The placement and movement of content in Augmented Reality, as well as the participants' workflow, user experience and satisfaction, were all examined in greater depth. The participants' sensemaking process contained numerous sensemaking activities and phases, which could be mapped to several sensemaking models presented in the theoretical background, according to the analysis of the collected data. As a result, the suggested system aids the user's sensemaking process while also providing beneficial features that could be improved in future work. In addition, four potential layout patterns for virtual content placement in Augmented Reality were discovered and compared to previous research. While the users were still aware of their surroundings, positioning and arranging virtual content into different groups aided the task solving and workflow integration. Although the device's size and means of holding it should be researched and optimized in the future, the engagement with the hand-held device allowed for better interaction with and reading of the study's information. A hybrid-user interface that combines a hand-held device with an Augmented Reality head-mounted display offers a promising environment for future sensemaking work, and should be investigated further, focusing on the hand-held device size, room and furniture settings and collaborative aspects.

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A Appendix

User Study Material

The documents used in the user study can be found on the following pages:

- Welcome letter

- Consent form

- Demographic questionnaire

- Interview questions

- The images added to the clues provided for the user study

Study Information

Welcome and thank you for participating.
During this study, you will have to answer multiple questions about a murder case. You will be provided with a data set containing of clues and images to work with. Additionally, you will work with a prototype consisting of a tablet application and a Hololens 2, which are augmented reality glasses. While working on the murder case scenario some data about your performance and approach will be recorded. All the information provided by you and the data collected are treated anonymously and will not give any conclusion on your identity.

Study Procedure

The study will start with some questions about your demographic background including additional questions important for the study setting. Afterward, the basic study setup will be explained and necessary precautions will be carried out (such as the Hololens 2 calibration).

Before working with the prototype you will be asked to position yourself on the marking on the floor while looking at the marking on the whiteboard in front of you. Then the training phase can be started.

The training phase consists of a Tutorial located on the tablet which you will have to go through to get to know all the features of the system. During this training phase, questions can be asked directly to the study advisor. After trying out the different features and feeling comfortable with the system, the central user task can be started.

The murder case scenario will be visible to you including the questions you will have to answer. Both information will also be available to you at any time on a sheet of paper located on the table. During this phase, you will be left alone to work individually on the murder case. You will have a total time of a maximum of 30 minutes to come to a solution. During this time data will be recorded using different cameras and data logging. At the 25-minute time mark, you will be informed about the 5 remaining minutes. After completing the tasks please pass on your answers to the study advisor.

Finally an interview will be held, where you will be asked to answer different questions about your experience as well as fill out an usability questionnaire. The interview will be recorded using a microphone. As a compensation you will receive 10 euros.

You have the right to abort the study at any point without naming a reason.
Please try to give your best while trying to solve the murder case as it will affect the study results.
The study will last about 1 hour in time

Figure A.1: Welcome Letter.

Consent form

I hereby confirm that I was informed about the study's content, duration and risks. Furthermore, I agree with the data recording which will take place during the study which consists of video/ audio recordings and data loggings. All the recorded data are treated anonymously and will not include any personal information. Furthermore, I agree to the usage of my data as part of the bachelor thesis "Design and Evaluation of a Hybrid User Interface for Individual Sensemaking Activities" including related presentations and any further related publications. Furthermore, I confirm that I was informed about the risk assessment and the associated precautions and rules.

Participant

Name:

Date and signature:

Konstanz,

Study Advisor

Name:

Selina Uecker

Date and signature:

Konstanz,

Figure A.2: Consent form.

ID: _______

1. What is your gender?

☐ Female ☐ Male ☐ Other

2. What is your age?

____

4. What is your occupation? If you are a student please name your major.

____

5. Do you wear glasses or contact lenses?

☐ Yes ☐ No

6. Do you have any kind of color deficiency?

☐ Yes ☐ No

Which one?

____

7. Do you have experience with Augmented Reality?

☐ Yes ☐ No

Where did you encounter it?

____

8. Have you worked with the Hololens 2 before?

☐ Yes ☐ No

Where did you encounter it?

____

Figure A.3: Demographic questionnaire (page 1).

9. How often do you work with technological devices (computer, tablet, phone)?

- ☐ Less than 1 hour per day
- ☐ Between 1 and 3 hours per day
- ☐ Between 3-5 hours per day
- ☐ More than 5 hours per day

10. How would you rate your technology skills?

- ☐ Poor
- ☐ Below Average
- ☐ Average
- ☐ Above Average
- ☐ Excellent

Figure A.4: Demographic questionnaire (page 2).

ID:______

Interview

1. Please describe your work strategy, what steps you you took and your thoughts behind it.

2. Please describe the thought behind your arrangement of content in AR.

3. How was the overall experience with the system. Did you face any problems or difficulties? What did you like/ dislike about the system?

4. Do you have any suggestions to improve the system?

5. Any further comments?

Figure A.5: Interview questions.

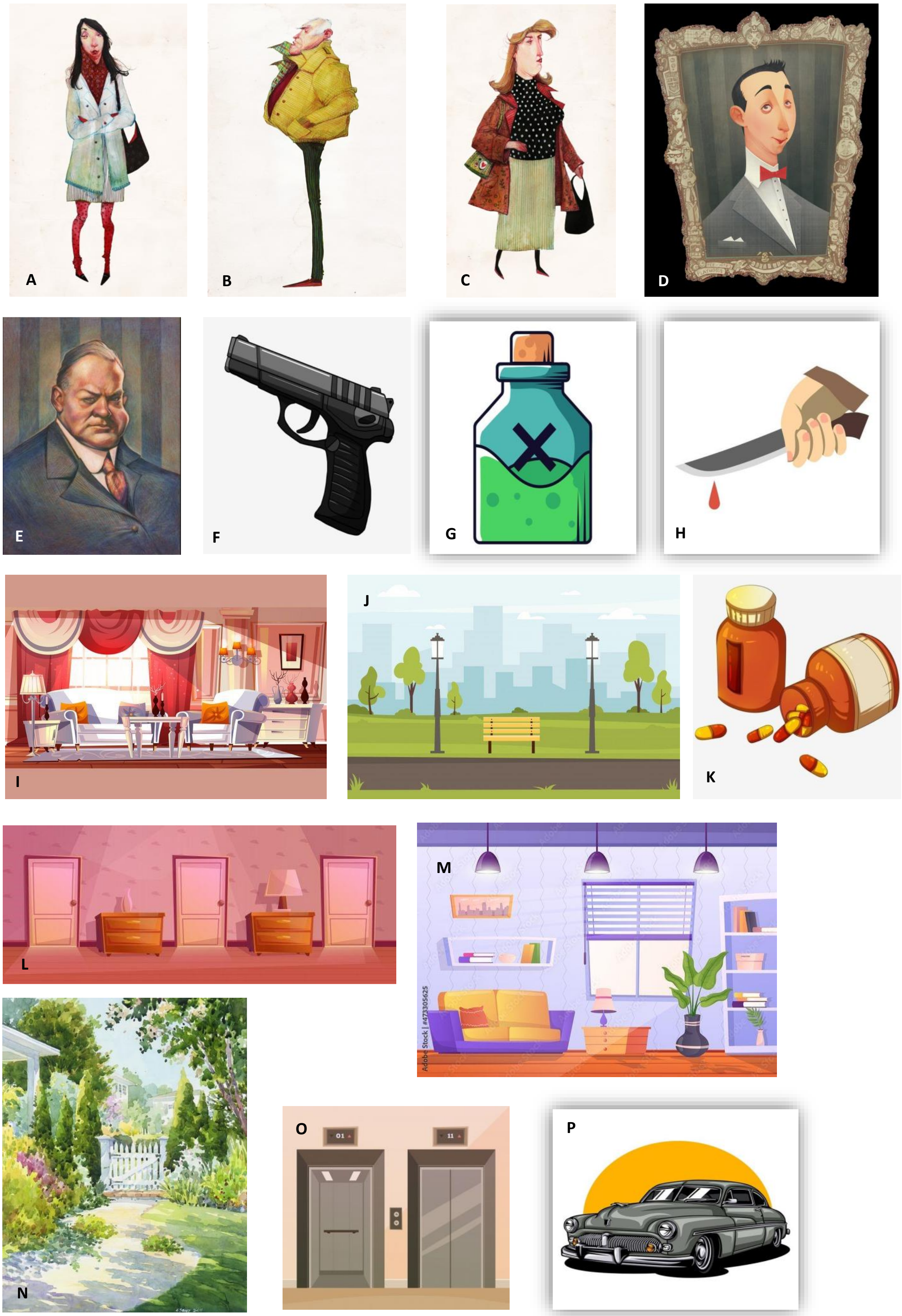

Figure A.6: The images added to the clues provided for the user study: Mr. Kelley's wife (A), Mr. Scott (B), Miss Smith (C), Elevator man (D), Mr. Jones (E), Mr. Jones' gun (F), Poison (G), Knife (H), Mr. Jones' apartment (I), Park (J), Drugs (K), Hallway (L), Mr. Scott's apartment (M), Miss Smith's yard (N), Elevator (O), Mr. Scott's car (P).

B Enclosure

The supplied USB device contains all necessary files for this project, including:

- A digital copy of this work (file name: Selina_Uecker_Bachelor_Thesis.pdf)

- The Seminar to the Bachelor's Project (file name: Selina_Uecker_Bachelor_Seminar.pdf)

- The Bachelor Project Report (file name: Selina_Uecker_Bachelor_Project.pdf)