# Designing Map-Based Visual Storytelling for News Articles in Mixed Reality

Vegard Sviland

Master's thesis in media- and interaction design

01-06-2023

Keywords: Mixed Reality, News, Storytelling, Maps

## Abstract

This study investigates how we can design map-based visual storytelling of news articles for Mixed Reality Head-Mounted Displays (MR HMDs). It explores the significance of visual storytelling genres and interactive gestures in the design. The findings reveal that principles of storytelling and interaction cannot be directly transferred from traditional PC interfaces to MR HMDs due to fundamental differences in interface and interaction. The study highlights the effectiveness of the dynamic slideshow format and far-interaction in enhancing the storytelling experience. Participants favored hand interactions but expressed interest in alternative methods such as gaze- and voice-based interactions. The challenges faced during the project, including recruitment difficulties, testing environment limitations, and technical issues, influenced the findings. The study emphasizes the need for tailored design principles for MR storytelling and multiple interaction methods to cater to user preferences. Overall, the findings provide valuable insights into designing map-based interactions in MR for visual storytelling, with consideration for the encountered challenges and limitations.

## Acknowledgments

I collaborated with Fay Tveranger, a co-student, throughout this project to make the prototype MR news. I want to express my gratitude towards Fay for a productive and fruitful partnership. When I refer to “we” in the thesis, I refer to Fay and me. We use the prototype to investigate separate research questions (RQ) in individual theses. I want to thank my project supervisors, Frode Guribye and Floris Hendrikus Johannes van den Oever, for their guidance throughout the project. Thank you to all 16 that participated in interviews, workshops, and user tests throughout the project. I want to thank Teklab for lending us their HoloLens 2, which made this project possible.

# Contents

# 1. Introduction

Mixed Reality (MR) is becoming more widespread in various industries such as education, healthcare, retail, automotive, manufacturing, aerospace, media, and entertainment. Extended Reality (XR) technologies, encompassing all immersive technologies, are expected to become even more popular with the widespread use of 5G technology. The XR market is rapidly growing and expected to reach approximately 345 billion USD in the next eight years, up from approximately 35 billion USD in 2022, according to Precedence (2022). Furthermore, the anticipated release of an MR Head Mounted Display (HMD) by Apple this year indicates an increased interest in using this technology by the general public (Kvalheim, 2023; Pritchard, 2023). Apple products have previously created new consumer markets and industries, such as personal computers, smartphones, tablets, and smartwatches (Mullaney, 2016), and it is possible that their entry into the MR market could drive similar developments.

MR shows potential for enhancing news engagement. News plays a fundamental role in informing us about global events and important societal topics such as politics, the economy, the environment, and health concerns. It offers diverse perspectives, allowing us to understand different opinions and cultures. Additionally, news informs citizens about government actions and ensures accountability. By integrating MR technology, news experiences can become more immersive and interactive, deepening the connection between the audience and the content. This has the potential to revolutionize news consumption and promote an informed and engaged society.

Recent research indicates an increasing trend, particularly among younger individuals, of reduced news consumption (Dæhlen, 2021). This poses significant concerns for society and democracy, as a lack of awareness and engagement with current events can influence individuals' capacity to make well-informed decisions. The media sector is faced with the imperative of developing effective solutions to engage the younger demographic.

News media utilizes diverse platforms such as TV, PC, smartphone, radio, and newspapers to present information in various formats such as articles, broadcasts, and social media “stories” to cater to consumers’ preferences and needs. With the rise in popularity of XR technologies, it becomes crucial for news media to explore and leverage these technologies to engage readers. Recent explorations by media companies have focused on XR as a frontier for storytelling, aiming to capitalize on its visual and interactive capabilities (Mordor, 2023).

In a study on immersive journalism conducted by Herrera Damas and Benítez de Gracia (2022), experts emphasized the importance of immersive experiences that enable interactivity, evoke emotional responses, provide new perspectives, and actively involve viewers in the content (Herrera Damas & Benítez de Gracia, 2022).

Maps and XR technology share powerful visualization- and interaction capabilities and offer an ideal combination for creating engaging user experiences. Similar to stories, maps serve as tools for documenting and elucidating experiences while expressing specific perspectives and worldviews (Roth, 2021).

The adoption of XR technologies in the media industry presents a need for new interaction design. Replication of 2D interfaces in XR platforms restricts their effectiveness for users. For instance, conventional formats like browsers and news articles designed for desktop computers do not fully exploit the potential of XR. It is key to tailor interface designs and functionalities explicitly for XR platforms to optimize their usability and user experience.

This study aims to investigate design considerations for map-based visual storytelling of news articles for MR HMDs in an attempt to enhance the news consumption experience. The primary objective is to investigate the integration of maps. To accomplish this, a Research through Design (RtD) study is conducted, involving the development and testing of a prototype named MR news with potential future users. The evaluation phase focuses on examining how visual story maps can be effectively designed based on visual storytelling genres and interactive gestures with potential future users. Afterwards, the results are analyzed and discussed in relation to existing research on visual storytelling with maps and interactive maps in XR.

The research question (RQ) is:
How can we design map-based interactions in regard to visual storytelling genres and interactive gestures for news articles in Mixed Reality?

In the background chapter, there will be given an overview of existing research on visual storytelling genres with maps and interactive maps in XR. The methodology chapter describe applied methods, introduce the prototype named *MR news,* the prototyping process, and evaluate the prototype. Afterwards, a discussion of the results towards related research, challenges, and future work. Lastly, a conclusion where the RQ is answered.

# 2. Background

This section will further introduce MR, briefly account for visual displays and maps, elaborate on visual storytelling with maps, and describe related research on interacting with maps in XR.

## Mixed Reality (MR)

Milgram et al. (1995) defined the Reality-Virtuality (RV) continuum, seen in Figure 1, which has become a widely accepted conceptualization of immersive technologies. MR is a term that describes immersive technologies, from Augmented Reality (AR) to Augmented Virtuality (AV). AR and AV have in common that they both mix the real environment with a Virtual Environment (VE). A real environment consists of only real objects in the real world, meaning it can be observed in person, through video displays, glasses, or windows. VE means that the entire environment comprises virtual objects or digital graphics unaffected by the real environment. It is commonly displayed through immersive Head Mounted Displays (HMD), which include Virtual Reality (VR) headsets. That means AR and AV technologies combine virtual elements with the real world. It can be displayed through digital displays, such as phones and HMDs. MR HMD can have transparent displays with digital overlays or video displays. AR differentiates from AV by being closer to a real-world environment, whereas AV is more comparable to VE (Milgram et al., 1995). Azuma (1997) defines AR as virtual objects superimposed on the real environment. Further describing three characteristics of AR, it combines the real environment and the virtual, is interactive in real-time, and is registered in 3D. Azuma (1997) further differentiates AR and VR by adding that AR supplements reality instead of replacing it.

The MR news prototype can be specified as an AR application because the general environment around the user is real, with an overlay of digital elements. However, when addressed in this study, I will use the more general term MR. This is because the HL2 is an MR HMD and can allow the MR news prototype to utilize both AR and AV.

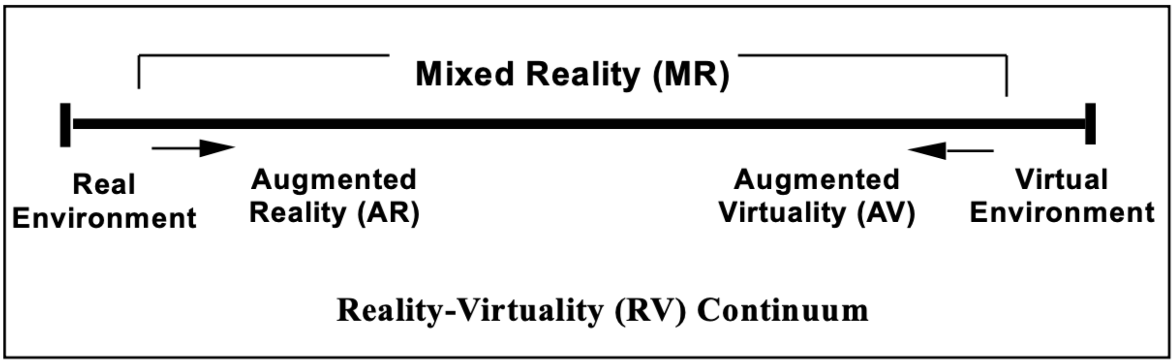



*Figure 1 – Reality-Virtuality continuum (Milgram et al., 1995).*

Many of the principles for design in XR HMDs are transferable and overlapping as they operate in a three-dimensional space and are immersive technologies. We choose to work with MR HMD because it is a promising technology for productivity and everyday use. It allows the user to be present in reality while engaging with the technology. It also allows the user to use an information display hands-free and heads-up. The MR market constituted approximately 73% of the total XR marked in 2021, demonstrating more interest in these technologies than in VR (Precedence, 2022).

We chose to work with HoloLens 2 (HL2) as it is an established MR HMD. HL2 is a self-contained holographic computer launched by Microsoft in 2019. It has see-through holographic lenses, meaning that users will see the real environment through a glass visor, and holographic elements are displayed on this visor by lasers. HL2 is also packed with different sensors to capture and map the real environment, place holograms throughout it, and enable motion tracking to capture user input (Microsoft, 2023). It also uses hand navigation instead of controllers, which we view as much more convenient and likely to be more popular and valuable in future developments in XR technology.

*Figure 2 – Example image of HoloLens 2 (Goode, 2019).*

## Visual Displays

Visual displays can include static and animated illustrations, and graphs, as well as geographical-, thematic-, and knowledge maps. These visual displays play a crucial role in enhancing one's cognitive abilities, learning skills, and prior knowledge. According to several theories on visual learning, such as dual coding, conjoint processing, and multimedia learning, visual displays can help in communication, thinking, and learning. Paivio's dual coding theory suggests that verbal and pictorial information are processed in different cognitive subsystems. Text is processed only in the verbal subsystem, while visual displays are processed in both an imagery and verbal subsystem. Therefore, visual displays are more easily memorized due to the dual coding of visual information (Schnotz, 2002).

## Maps

According to Roth (2013), cartography is the practice of creating and using maps. It was recognized as a scientific discipline after WW2. Functional design was one of the guiding principles for map design, with guidelines based on designing for the intended users. As maps are a visual form of communication, they can facilitate cognitive offload and effective learning. New technologies have led to numerous and substantial changes in the creation and usage of maps. Interactivity is one of the most significant changes in how we use maps. Although one also interacts with analog maps, the extent of possibilities for interaction is a lot more in digital maps. Further, the extent of interaction possibilities increases drastically from 2D screens to immersive XR technologies (Roth, 2013).

## Visual Storytelling

Roth (2021) describes visual storytelling as simplifying complex data and capturing attention through maps and other visualizations such as images, illustrations, animations, and models to create a better sense of place. It ties seemingly unrelated information together in a memorable way. Roth (2021) offers three methods for map-based visual storytelling. First, identify and connect narrative elements to geographical information. Second, genres for different story experiences. The third and final are visual tropes that can enhance the storytelling.

Visual storytelling design relies on narrative sequences in the story. Most stories have a common set of basic elements organized through narrative. In most cases, narrative sequences are analyzed using a linear three-act structure. A three-act narrative consists of a beginning, middle, and end or set-up, conflict, and resolution. Each has recurring narrative elements across stories that can be visualized. Identifying such narrative elements and creating visualizations through maps and other multimedia is important for consistent and effective visual storytelling and can improve the users' experience and retention of the story (Roth, 2021).

Song et al. (2022) conducted a study to test the three methods proposed by Roth (2021). They found that a three-act narrative can be applied consistently and effectively across topics and did not affect the participants' retention. However, they found that genres and to some extent tropes influenced the participants' retention (Song et al., 2022).

Roth (2021) proposes seven genres defined by the visual or interactive practice of applying a linear narrative. The genres are static visual stories, longform infographics, dynamic slideshows, narrated animations, multimedia visual experiences, personalized story maps, and compilations.

Static visual stories are a series of maps that use different annotations such as arrows, numbering, and other visual techniques throughout the story. Longform infographics include all text, graphics, maps, and so on in a single-page vertical scroll setup. They are typically used for smartphones in news and other websites as it is optimized for small screens. Dynamic slideshows advance a linear story through a series of visual panels or slides. They typically have a horizontal direction and display one slide at a time, meaning it is not a dynamic scroll interaction but usually a slide or tap navigation. This gives the designer more control over the story's pacing than longform infographics. Narrated animations display animations of progression over time. They are typically considered more intuitive and enjoyable than static maps. However, they can tend to be too complex for users to comprehend as they move along at the designers' pace rather than their own. This can lead to users missing important information and becoming biased toward the first and last frames when recalling the visual story. Multimedia visual experiences actively use hyperlinking in the storytelling, from hyperlinked text, images, graphics, audio, and video in addition to the central textual narrative and use dynamic vertical scrolling, like longform infographics. Multimedia visual experiences can lose some users from the main narrative as there can be many sidetracks competing for the users' attention. Personalized story maps allow non-designers to create visual stories of their experiences and share their perspectives. It is increasing in popularity. However, it can lead to poor data quality and limits creative flexibility. Compilations are often used in data journalism to show events as they happen. They are made up of visual stories with links to more information. They use maps to show what’s happening and are easy to update with new content. See Figure 3 for visual examples of the seven visual storytelling genres and Figure 4 for a comparison between them.

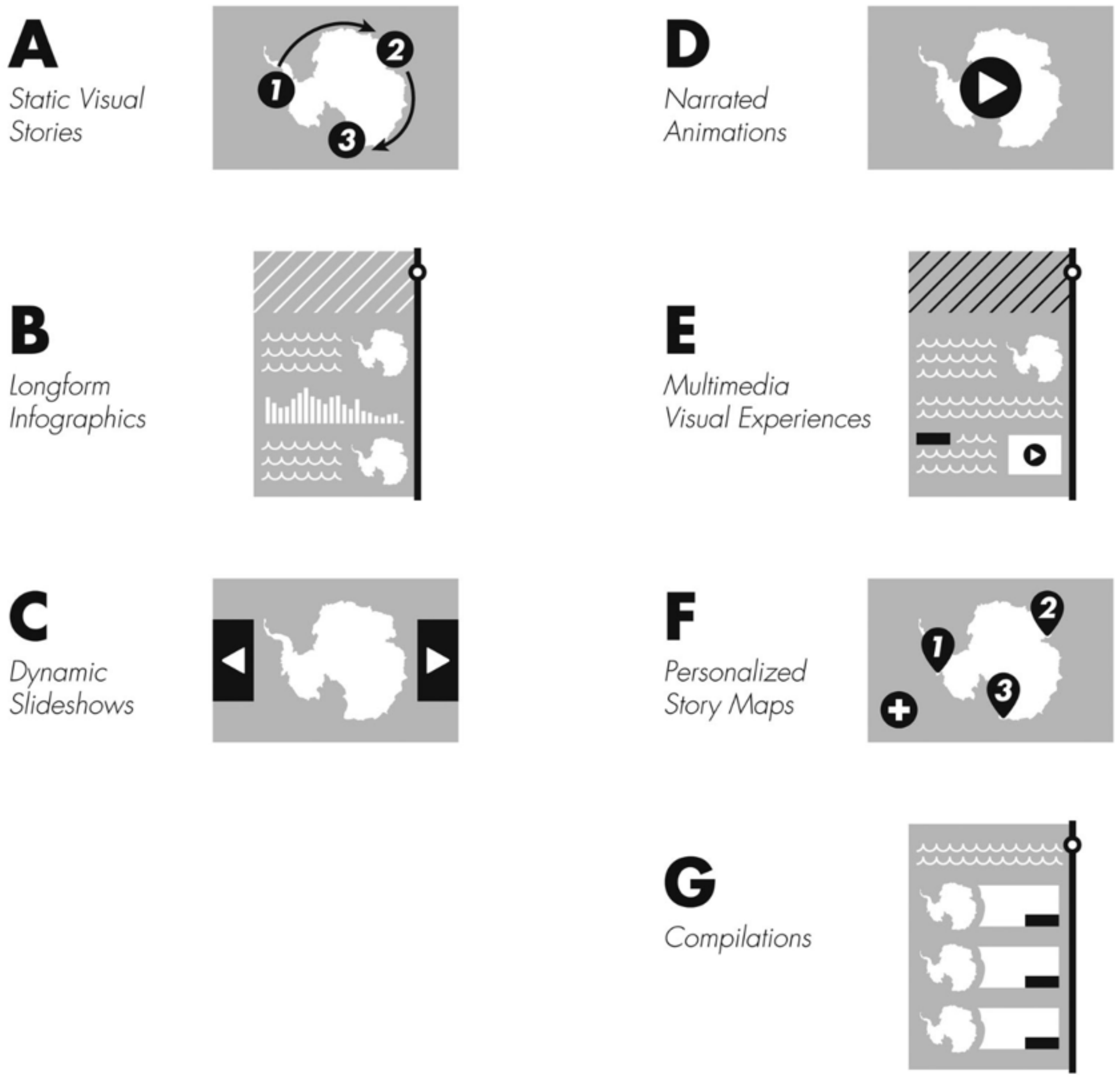



*Figure 3 – Visual examples of seven genres (Roth, 2021).*

| Genre | Linearity Definition | Fragment/Fluid | Pros | Cons | Example |
|---|---|---|---|---|---|
| Static Visual Story | Enforce linearity through partitioning of the layout into frames and clarifying reading with annotation | (1) Small multiple maps (fragmented), (2) central map with annotation (fluid), (3) inset map used in a supporting role among other frames (fragmented) | • Displays all content for visual comparison<br>• Familiar to audience<br>• Does not require web development skills<br>• Draws from existing cartographic design conventions, particularly flow mapping<br>• Good for introducing the setting and providing spatial reference for plot points<br>• Can be interactive through dashboard tools<br>• Easiest to respond between print and digital media | • Poor for showing movement and trends (small multiples)<br>• Emphasizes stability over change (small multiples)<br>• Often devoid of embellishments (small multiples)<br>• Most susceptible to breakdown in linearity<br>• Relies on focusing attention techniques that may impede or be missed by the audience<br>• Does not respond well for small screen and mobile viewing | 'The Melting of America' published in *National Geographic* (Tierney and Treat, 2017) explains the increased susceptibility of Antarctic ice to climate change. The static visual story uses layout, negative space, and annotation to enforce linearity. A comparison of the original static magazine version to a narrated animation of the same content is described in Tierney (2018; see Figure 3). Source: https://doi.org/10.14714/cp89.1469 |
| Longform Infographic | Enforce linearity through vertical reading and browser scrolling | Fluid or fragmented | • Digitally native and mobile-first<br>• Optimized for small screen and mobile viewing<br>• Intuitively support 'quest' plotlines (strip maps)<br>• Continuous interactive pacing by audience<br>• Grab-and-drag scrolling intuitive on mobile devices<br>• Inclusion of slippy web map supports drill-in and martini glass storytelling | • Majority of content is offscreen at any time<br>• Increased skimming, leading to missed plot points<br>• Exhibits 'quicksand' issue for embedded slippy web maps, leading to shift of scrolling focus | 'How Trump Redrew the Electoral Map, from Sea to Shining Sea' published online by *The Washington Post* (Gamio and Keating, 2016) uses two maps with novel symbolization to illustrate the shift in party voting in the US Presidential Election from 2012 to 2016. The maps are oriented east-up and read like strip maps, with linearity enforced through browser scrolling. Notably, the scrolling mimics the closing of polls from Eastern to Pacific time zones, adding a temporal dimension to the linear storytelling. Source: https://www.washingtonpost.com/graphics/politics/2016-election/election-results-from-coast-to-coast/ |
| Dynamic Slideshow | Enforce linearity by advancement through a series of slides | Fragmented | • Controlled dosing by designer<br>• Reduced skimming, leading to regularized delivery of plot points<br>• Saves mobile data plans when audience does not want to review entire story<br>• A portion of the layout or interface can remain persistent for context and non-linear breaks from the narrative (e.g., Esri StoryMaps) | • Majority of content is offscreen at any time<br>• Uses discrete (clicking, tapping, keying, swiping) rather than continuous interaction, increasing workload<br>• Difficult to advance or backtrack multiple frames<br>• Loading lags, breaking audience attention<br>• Reduced retention and preference (compared to longform infographic) | 'Amazonia Under Threat' published online by *National Geographic* (Baptista *et al.*, 2015) describes risks to biodiversity and the environment from human activities in the Amazon basin. The dynamic slideshow uses a persistent interface docked on the right to enforce linearity. The slide content is dynamic, enabling a break from linear storytelling through vertical scrolling, map panning and zooming, and animations. Source: https://www.nationalgeographic.com/climate-change/explore-amazonia/#/ |
| Narrated Animation | Enforce linearity by the progression of digital display time | Fluid; breaks between scenes | • Display time can congruently represent real-world time in the story<br>• Intuitive, enjoyable, and compelling<br>• Display time can explain process, fly-through a landscape, or fluid transition between frames<br>• Draws on film techniques and integrates audio-visual content for a compelling story<br>• Embeds designer's voice into the visual story<br>• Good for showing movement and trends | • Difficult to compare any two frames<br>• Passive pacing controlled by the designer<br>• Majority of content is offscreen at any time<br>• Biased by first and last frame when interpreting and recalling the visual story<br>• Interactivity interferes with narration<br>• Difficult to create, requiring special software and technical skills | Videos from 'The Joy of Stats' videos published on GapMinder.org (videos collected 2010–2018; accessed July 1, 2018), which use statistics and visualization to describe worldwide sociodemographic changes over the past two centuries. Linearity is enforced through display time in the narrated animation. Beyond just voice narration, Hans Rosling inserts himself into the animated graphics, further humanizing the visual story. Source: https://www.gapminder.org/videos/the-joy-of-stats/ |
| Multimedia Visual Experience | Enforce linearity by anchor tags and hyperlinking | Fragmented across webpages; fluid within page | • Web-enabled and multimedia<br>• Uses an immersive array of images, graphics, audio, and video that accompany and amplify a central textual narrative<br>• Mashes up easily with other genres<br>• Supports both martini glass and drill-drown storytelling structures<br>• Continuous interactive pacing by audience<br>• Embeds designer's voice, as well as the voices of people described in the story<br>• Develops a deep sense of place | • Includes more text than other genres, with most content offscreen and on different webpages<br>• Exhibits 'quicksand' issue for embedded slippy web maps<br>• Higher attrition or bounce rate than other genres<br>• Map is usually supporting rather than central to the narrative<br>• Requires rich set of quantitative and qualitative primary information that the designers need to collect | 'Snowfall: The Avalanche at Tunnel Creek' published online by *The New York Times* (Branch, 2012) details the experiences of skiers and snowboarders trapped in an avalanche in Washington State (US). The multimedia visual experience uses a compelling array of text, images, maps, and videos, activating dynamic content through anchor tags and hyperlinks while scrolling. Source: http://www.nytimes.com/projects/2012/snow-fall/ |
| Personalized Story Map | Enforce linearity by the order that an individual contributes content to the map | Fluid | • Can be made by non-experts untrained in design<br>• Embraces pluralism and promotes multiplicity<br>• Makes use of a central map to activate all content<br>• Interactive pacing by audience<br>• Georeferencing facilitated by mobile-first story mapping services<br>• Exhibits elements of gamification and playful maps<br>• Popular for education and research outreach | • Limited design flexibility<br>• Regularized pacing by the point-based story map platform<br>• May have poorer quality, misleading symbolization, and inherent narratives<br>• Potentially erodes privacy and enables surveillance | 'Snap Map' maintained by SnapChat (accessed July 1, 2018) is a platform for sharing photos and videos as georeferenced visual 'stories' that last for 24 hours. The service aggregates clusters of stories to represent current events for viewing online, with the linearity of these events enforced by the order of user contributions. In the mobile application, users can embed themselves into the map using an avatar, sharing their location with friends at a high spatial precision as they contribute visual media. Source: https://map.snapchat.com/ |
| Visual Story Compilation | Enforce linearity by unfolding events in near real-time or major updates to the design | Fragmented | • Best for extreme events or recurrent themes<br>• Organizes disparate visual stories around common activities, themes, or places<br>• Provides a visual summary of changing conditions, "putting the audience" into the narrative as it unfolds and inviting them to return for updates<br>• Utilizes and organizes existing content while allowing easy integration of new content | • Narrative and pacing emerges from the events, rather than from designer<br>• Fragmented layout dividing content across multiple webpages | 'Maps: Tracking Harvey's Destructive Path Through Texas and Louisiana' maintained by *The New York Times* (Aisch *et al.*, updated August 25-31, 2017) tracks the development and impact of Hurricane Harvey in the Gulf region of the US. As the event unfolds, map updates are placed at the top of the compilation, enforcing linearity from newest to oldest updates. Many of the maps in the compilation link to other content from *The New York Times*, enabling non-linear storytelling. Source: https://www.nytimes.com/interactive/2017/08/24/us/hurricane-harvey-texas.html |

*Figure 4 – Comparison of visual storytelling genres (Roth, 2021).*

Roth (2021) describes seven visual tropes that can improve and enhance the narrative and visual elements. The tropes are continuity, mood, dosing, attention, redundancy, metaphor, and voice. Continuity unifies visual elements into a logical structure. It can enhance the memorability of the visual story. It can be achieved using linear narrative genres, such as those mentioned above. Additionally, it can be achieved by using visual transitions such as fading, panning, and zooming can promote continuity between elements. Mood sets the visual tone of a narrative, influencing the users' instant reaction. Map elements and design choices contribute to setting the mood. The visual style, including form, color, type, and texture, plays a significant role in evoking emotions. Dosing simplifies information by breaking it into smaller parts and focusing on important elements. It emphasizes specific elements, not just overall patterns, to build interest and understanding. Interactive maps can also provide "self-dosing" by using pop-ups for more information. To ensure the users notice and focus on important information, it is essential to draw their attention. It can be done by controlling the visual hierarchy, or the flow in the layout, by framing, highlighting, blinking, panning, and zooming. Redundancy is the repetition of important details to enhance visual storytelling and make it more impactful, understandable, and engaging. Metaphors are tools in visual storytelling that combine unrelated concepts to enhance understanding. It can be symbolic representations like overlays, exaggerations, and cartooning. It can help to create compelling metaphors that captivate the users. Voice includes experience, opinions, and values in the visual story to enhance understanding. Different voices can be represented through varying text attributes. Dynamic techniques inspired by cinematic cartography involve audio or audiovisual elements (Roth, 2021).

In the study by Song et al. (2022), they tested two genres, longform infographics and dynamic slideshow. They found that participants had better retention and performed better with longform infographics, as it was a familiar format with easy and low effort interaction (Song et al., 2022).

## Related research

XR HMDs facilitate for exploration of large information spaces, such as maps. They can offer a more natural and comfortable way for users to get a better spatial understanding of information. However, to exploit this technology, a different approach to designing interaction and input is required (Giannopoulos et al., 2017).

Rudi et al. (2016) studied interaction with maps in MR, especially on how interactions such as panning, zooming, and both panning and zooming compared between head-based- and haptic (touch-based) interactions. The head-based interactions included nodding in different directions, depending on what they wanted to accomplish. They found that as long as what the users saw on the screen was well aligned with the movements they made that the interactions with the map, head-based interactions allowed for more efficient and effective navigation (Rudi et al., 2016).

Zhou and Bai (2023) argue that it is necessary to approach the design of natural gesture interaction from the user's perspective to improve user acceptance and user experience. Further mentioning that many other studies, such as the study by Rudi et al. (2016), chose a more efficient approach by getting input from experts rather than user-centered. In the study by Zhou and Bai (2023), they investigate users' natural means of gestures when interacting with 2D maps in HMDs in multiple sizes using far-interaction. All the participants used hand interactions but found that the interactions varied based on the size of the maps. Generally, they used larger physical movements if the maps were larger. They focused especially on zooming-, rotation-, and panning gestures. In the smallest maps, they found that it was most common for the participants to gesture with only one hand, either with their entire hand or only their index finger (and thumb when zooming) in pinching and swiping motions. In the mid-sized and big maps, most participants used their entire hand when zooming, and many started using two hands to zoom. Many participants also started using two hands to rotate. The participants favored using their entire arm, not just the hand. However, most preferred singlehanded interaction, and the participants used very similar motions for the different navigations. They also found that zooming and rotating were most widely used when navigating, while panning was less frequent (Zhou & Bai, 2023). Figure 5 illustrates the most frequent hand gestures in the different-sized maps.


*Figure 5 – Example of the most used hand gestures in different map sizes, from A-F, where A is the smallest and F the largest (Zhou & Bai, 2023).*

In a study by Yang et al. (2020), they explore different approaches to visualize data using maps in VR. The data they visualize is a population density by state in the USA. They explore 2D choropleth maps and 3D prism maps to determine the better way to represent area-linked data. Choropleth maps use different colors that illustrate different values. Prism maps illustrate values by displaying differences in elevation. They found that participants were more accurate when using the prism map and that they preferred a colored prism map. However, participants worked faster with the choropleth map. Additionally, prism maps can cause occlusion, meaning that elevations can hide parts of the map behind, which raised some concerns among some participants. To satisfy all needs, they created Tilt Map. It combines the maps, where the participants can choose how they want to view it. When the map faces the user vertically, displayed in 2D, the user can further tilt it by moving their hand downwards. When the map is tilted it displays the data in 3D. That way, users can choose how they want to display the data at any time. They also tested a comparison between Tilt Map, a side-by-side view of the maps, and a toggle between the maps. In the tests, they found that participants preferred Tilt Map as it gave the users more freedom when tilting and rotating the map than the other two. Additionally, they made it harder to track what they were focusing on (Yang et al., 2020). Figure 6 illustrates the functionality of Tilt map.

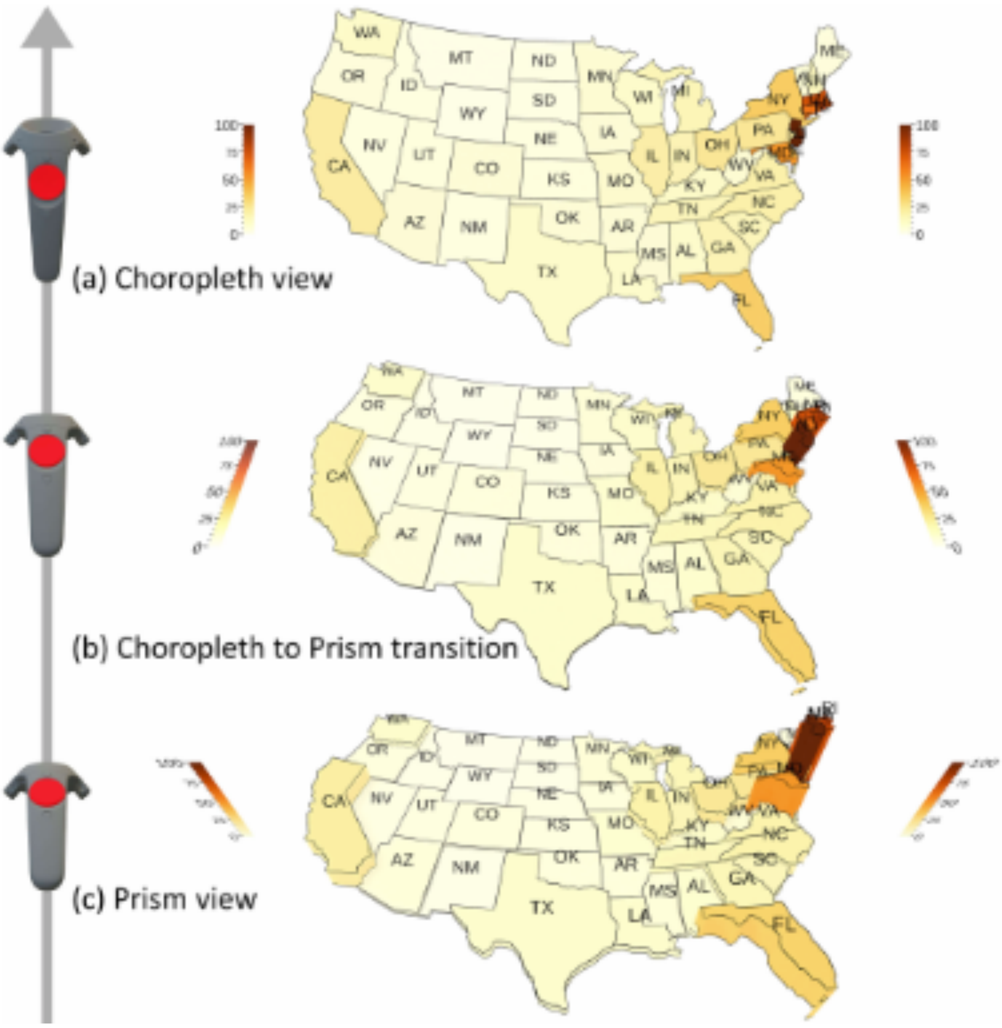



*Figure 6 – Example of how Tilt Map works (Yang et al., 2020).*

An example of a solution for a 3D map in MR is called HoloMaps, which was made by Taqtile. It is an interactive holographic 3D map that can overlay real-time data such as weather, traffic, and geo-tagged tweets. Holomaps includes 200 cities and landmarks as 3D models. Additionally, it can be seen by multiple people simultaneously in the same room or remotely and offers the possibility to take notes, annotations, and drawings in 3D ink. HoloMaps was launched in 2016 in the Microsoft store (Taqtile, 2016), but Taqtile has stopped the projects because of funding issues. It can still be found in the store but will no longer run on HL2.

*Figure 7 – Two examples of HoloMaps by Taqtile. (Taqtile, 2016)*

# 3. Methodology

In this chapter, I will go through the methods used in the MR news project. That includes Research through Design (RtD), Participatory Design (PD), Prototyping, Thematic Analysis (TA), and further present an overview of the data collection.

## Research through Design

Research through design (RtD) is a research method that utilizes practices, methods, and processes from design practice in order to gain new knowledge and insights. It is an iterative process that consistently reevaluates and reframes a problem space. This is done by evaluating artifacts that act as suggested solutions (Zimmerman & Forlizzi, 2014). RtD is an interaction design research approach that focuses on design artifacts as results that can transform something from the current state to a preferred state. RtD enables the HCI research community to handle explorative tasks, which is hard to do with science and engineering methods (Zimmerman, 2007). Explorative tasks can refer to complex problems which are hard to define, comprehend and solve. In RtD research the goal is to find an optimal solution for the current situation and not to discover the truth. RtD depends on design methods to approach chaotic situations unsuitable for other methods. It also requires that the researchers focus on the future and not the present or past. The artifact resulting from RtD can be seen as a proposition for a preferred state or a placeholder that opens a new space of design where other designers can better define the relevant phenomena. Because RtD allows for the exploration, prototyping, and evaluation of proposed solutions, it can provide a deeper understanding of the problem space, leading to better solutions (Zimmerman, 2010). Some RtD practices that can be followed are Koskinen et al. (2011) Lab, Field, and Showroom framework. These are based on Rich Interaction (Lab), Participatory Design (Field), and Critical Design (Showroom) (Zimmerman & Forlizzi, 2014). We used Participatory design for this project which will be elaborated on in the next section below.

Zimmerman and Forlizzi (2014) suggest five steps to carry out an RtD project. Select, design, evaluate, reflect and disseminate, and finally repeat. Select involves choosing a research problem and what material, context, and target population to focus on. Additionally, choose one or more RtD practices to follow, Lab, Field, and/or Showroom. Design includes conducting a literature review of the state of the art in the design space. Further, explore the space by conducting fieldwork such as workshops. Afterward, create a new product/service and iterate, evaluate, and critique it. Once the artifact reaches a satisfactory level, it can be evaluated in the chosen practice (Lab, Field, or Showroom) and concerning the research question. After reflecting on the data gathered to learn how to improve the artifact in the next iteration, the next step is to repeat the process (Zimmerman & Forlizzi, 2014).

## Participatory Design

Participatory Design (PD) focuses on actively involving users in forming and investigating design ideas. It is a practice where interdisciplinary teams design systems with future system users to increase performance and productivity. PD emerged in Scandinavia as workers deemed that the IT systems they used were not efficient, and lacked features and flows for their work tasks which made the workers unable to reflect their experience and skills through these systems. As a reaction, a new approach to the design was tested where some workers, selected by their colleagues, were included in the design process as expert users to give insights on work practices in the organization. In this approach, they evolved a system iteratively, working from low-fidelity prototypes to a whole concept. That way, they didn't have to commit to a technology before it was tested through several iterations, resulting in a better system for the workers (Zimmerman & Forlizzi, 2014).

Following a field/PD practice usually involves gaining user insights through workshops and interviews. It is important to interpret and evaluate the results to understand the users' values and needs, not directly incorporate their ideas in the design. Additionally, place a working prototype in the field, meaning in the context they are intended to be used, and evaluate how it is used and if it brings out the intended behaviors and outcomes (Zimmerman & Forlizzi, 2014).

The target audience for this study consisted of young adults aged between 20 and 35, who are generally more inclined to explore new technologies and possess good digital competence. They are also among the early adopters of new technologies (YouGov, 2020). Additionally, we sought individuals who are interested in new technologies and consume news regularly. This demographic aligns with potential future users of the MR news system. To engage with this target group, we conducted workshops, interviews, and user testing throughout the project. Most of the participants who took part met all the criteria of our target group, while a few only matched with two.

## Prototyping

Prototyping is how designers can learn naturally and progressively to discover, create, and improve designs. The term prototype is often used to describe an object used in the design process. It is used in many fields, such as HCI, to conduct research. There have been many different propositions for prototyping techniques, such as low- and high-fidelity prototypes. Common among these techniques is that they are mainly used to evaluate the success or failure of the designs. Prototyping enables design thinking and should be used for much more than just evaluating the success and failures of designs (Lim et al., 2008). There has been a focus on fidelity mainly as It Is a matter of cost. In an article by Lim et al. (2008), they argue that a mixed-fidelity approach is more effective, whereas low- and high-fidelity is too simple. They propose a framework that they call the Anatomy of Prototypes. In the framework, they describe three core principles. Fundamental Prototyping Principle (FPP), Economic Principal of Prototyping (EpoP), and Anatomy of Prototypes (AoP). They are defined as:

> FPP: "Prototyping is an activity with the purpose of creating a manifestation that, in its simplest form, filters the qualities in which designers are interested, without distorting the understanding of the whole"
>
> EpoP: "The best prototype is one that, in the simplest and the most efficient way, makes the possibilities and limitations of a design idea visible and measurable."

> AoP: “Prototypes are filters that traverse a design space and are manifestations of design ideas that concretize and externalize conceptual ideas.” (Lim et al., 2008)

They further explain two aspects of prototypes, Prototypes as Filters (PaF) and Prototypes as Manifestations of Design Ideas (PaMoDI). Because design spaces often are vast, it is important to map out a concept fully and choose or filter certain parts of the concept to focus on. PaF considers five filtering dimensions, appearance, data, functionality, interactivity, and spatial structure (Lim et al., 2008).

| Filtering Dimension | Example Variables |
|---|---|
| *Appearance* | size; color; shape; margin; form; weight; texture; proportion; hardness; transparency; gradation; haptic; sound |
| *Data* | data size; data type (e.g., number; string; media); data use; privacy type; hierarchy; organization |
| *Functionality* | system function; users’ functionality need |
| *Interactivity* | input behavior; output behavior; feedback behavior; information behavior |
| *Spatial structure* | arrangement of interface or information elements; relationship among interface or information elements—which can be either two- or three-dimensional, intangible or tangible, or mixed |

*Figure 8 – Examples of each Filtering Dimension (Lim et al., 2008)*

PaMoDI describes how prototypes should be executed through three manifestation dimensions—material, resolution, and scope. Material is defined as the medium used to create a prototype. Examples of mediums can be physical, paper, or computational, such as Figma or Unity. Resolution refers to the level of detail or fidelity of the prototype. The scope covers what should be manifested in the context (Lim et al., 2008).

## Thematic Analysis

We utilized Thematic Analysis (TA) to evaluate the data we gathered from the data collection. TA is a commonly used method for analyzing qualitative data and is applicable in various research fields and can be combined with many methods for data gathering. Project sample size recommendations when using TA are six to fifteen interviews and/or three to six focus groups/workshops (Clarke et al., 2015). Clarke et al. (2015) describe 6 phases of conducting a TA. Familiarization, coding, searching for themes, reviewing themes, defining and naming themes, and writing a report (Clarke et al., 2015).

First, we reviewed all the data we gathered, including transcriptions, notes, audio recordings, and video recordings. At the same time, we highlighted and took notes of interesting data. By doing this we could ensure we would not forget important information. Further, we would code the relevant findings, which means that we made short comments about the various findings to describe the findings in concise terms. We did this to find patterns more easily in the findings, which was the next step. To search for themes, we would categorize similar codes together. This made it more apparent that there were some frequently appearing subjects. Further, we would assess the themes. This way, we could see if some themes were similar or should be further divided. Once we had properly reviewed the themes we would define and name them. At last, we wrote a report on our findings describing the themes. By doing that, we could easily read about our findings when we started a new iteration, making it easier to scope the problem space for the coming iteration.

## Data Collection

Following the RtD framework illustrated in Figure 9, we would first scope the problem area, design a prototype, evaluate it, and reflect on the results, before starting a new iteration. Through this framework, we carried out a series of tasks to gather data, which are described in table 1-4.

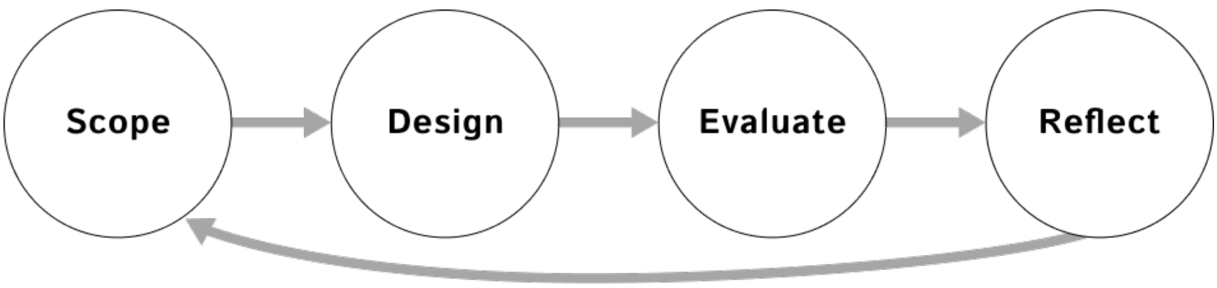



*Figure 9 – Research through Design framework.*

| Iteration (Ix) | Phase | Method | Quantity (Duration) | Description |
|---|---|---|---|---|
| I1 | Scope | Lecture and discussion with experts | 1 (1 hour) | Presentation and discussion led by NRK on the state-of-the-art of accessibility on their web platform and challenges regarding consuming digital news for people with different disabilities. |
| | | Expert Interviews | 5 (20 minutes) | Semi-structured Interviews with the target group |
| | Design process | Prototyping | | Design activities to develop a mock-up in HL2. |
| | Evaluation | Use Case Workshop | 5 (30 minutes) | Semi-controlled exploration of a mock-up of news article in HL2. |
| | | Interviews | 5 (30 minutes) | Semi-structured interviews where both specific parts of the mock-up and accessibility aspects and user experience were discussed |
| | Reflection | Thematic analysis | | Analyzed results by conducting thematic analysis. |

*Table 1 – Data collection from the first iteration.*

| Iteration (Ix) | Phase | Method | Quantity (Duration) | Description |
|---|---|---|---|---|
| I2 | Scope | Review of field report from I1 | | Reviewed the results from I1 in order to define a clearer scope. |

| | | | | |
|---|---|---|---|---|
| | Design process | Designer workshop | 1 (1 hour) | Design sprint to visualize a design and use case. |
| | | Design workshop | 2 (40 minutes) | The participants read an article and create a concept on how it would be experienced in AR and visualize it by drawing it on paper. Then a mental walkthrough of the concepts. |
| | Evaluation | Concept-demonstration | 2 (20 minutes) | Demonstration and discussing the designs produced in the designer workshop. |
| | Reflection | Thematic analysis | | Analyzed results by conducting thematic analysis. |

*Table 2 – Data collection from the second iteration.*

| Iteration (Ix) | Phase | Method | Quantity (Duration) | Description |
|---|---|---|---|---|
| I3 | Scope | Review of field report from I2 | | Reviewed the results from I1 and I2 in order to define a clearer scope. |
| | Design process | Prototyping | | Exploring potential approaches and framing the scope of the prototype (MVP) from the findings from I2. |
| | | Prototyping: development sprint | | Implementing design decisions from the design process. |
| | Evaluation | User evaluation of prototype | 3 (30 minutes) | User test of the prototype. The users were all tasked to read the article and explore the prototype. |

| | | | | |
|---|---|---|---|---|
| | | Interview | 3 (30 minutes) | Semi-structured interviews regarding the user experience of the prototype. |
| | Reflection | Thematic analysis | | Analyzed results by conducting thematic analysis. |

*Table 3 – Data collection from the third iteration.*

| Iteration (Ix) | Phase | Method | Quantity (Duration) | Description |
|---|---|---|---|---|
| I4 | Scope | Review of field report from I3 | | Reviewing findings from the last workshops and interviews to prepare the scope for the last iteration of prototype development. |
| | Design process | Design workshop | | Evaluated both the system as a whole and each component using the findings from the last evaluation. |
| | | Prototyping: development sprint | | Implementing functionality and design, grounded in the results from the design workshop. |
| | Evaluation | User evaluation of prototype | 7 (30 minutes) | The users were given two tasks: first they read the article and explored the prototype, then they were asked to adjust the set-up to their own liking. As they did both tasks, they were asked to "think-out-loud". |
| | | Interview and discussion | 7 (30 minutes) | Semi-structured interviews consisting of going through each component of the prototype, then moving on to questions |

| | | | | |
|---|---|---|---|---|
| | | | | regarding self-assessment, and more general questions regarding the user experience. |
| | Reflection | Thematic analysis | | Analyzed results by conducting thematic analysis. |

*Table 4 – Data collection from the fourth iteration.*

# 4. Prototyping Process

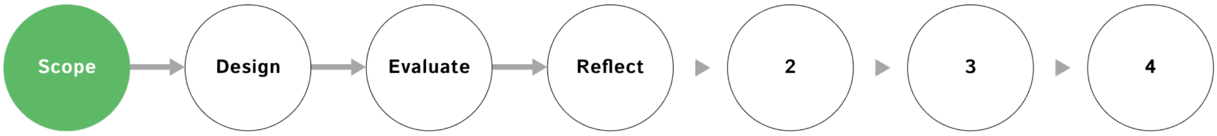
In order to execute the practical component of this research, which entailed the prototyping process, a collaborative effort was undertaken with a co-student named Fay. Our shared objective was to develop a prototype that could cater to the requirements of our respective studies. The prototype adopted a comprehensive approach, with the aim of investigating how news articles could be adapted in Mixed Reality (MR) to enhance accessibility, particularly for users with dyslexia, while also incorporating map-based storytelling. Initially, I was conducting research on the integration of maps into news content within mixed reality environments, with the goal of enhancing text comprehension for individuals with dyslexia. However, as my work progressed, my focus shifted towards how we can design map-based interactions in Mixed Reality for visual storytelling.

Throughout the prototyping process, a total of four iterations were conducted. Each iteration adhered to a structured framework encompassing four distinct stages: Scope, Design process, Evaluation, and Reflection. Across these iterations, we actively engaged with sixteen participants. One participant contributed to all four iterations, whereas three participants took part in two iterations each.

## Iteration 1

During this iteration, our focus was primarily directed towards the initial scoping of the project's problem space. To accomplish this, we employed a simple prototype and carried out a series of five user test evaluations. The purpose of these evaluations was twofold: to assess the viability of the concept and to determine the appropriate course of action moving forward.

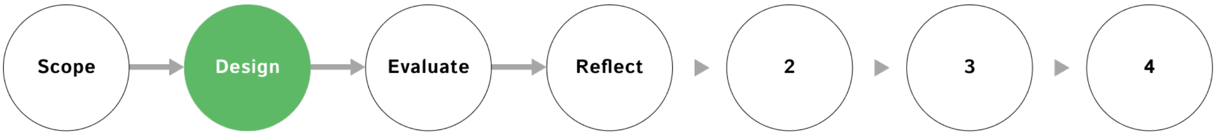
## Scope




The news media, such as NRK, is consistently striving to enhance the conveyance of news articles in order to make them more entertaining, comprehensible, and accessible. During the initial phase of our project, NRK, along with a few other organizations, delivered a presentation and lecture on a research area they were keen to explore further. They sought feedback from individuals with cognitive disabilities, particularly those struggling with dyslexia, who expressed difficulties in reading certain articles, typically those featuring numerous animations and moving text. To gain a deeper understanding of this issue, we attended a lecture conducted by experts on dyslexia from Dysleksi Norge, where our inquiries were addressed. This endeavor enabled us to comprehend the daily struggles experienced by dyslexic individuals and their coping mechanisms.

The complexity of this problem space piqued our interest. Further, we identified the potential benefits of employing Head-Mounted Displays (HMDs) as a tool to enhance accessibility for individuals with dyslexia. By incorporating more visual learning opportunities, encompassing immersive, interactive, and multisensory experiences, this technology has the potential to augment comprehension for this specific population. We centered our efforts on news articles containing geographical information, recognizing the advantages of integrating maps to improve comprehension for individuals with dyslexia. To further investigate this concept, we have embarked on creating a prototype and conducting interviews and workshops involving individuals with dyslexia, as well as regular news consumers and interaction designers. The goal of this iteration was to gather important information that could help us improve and make progress.

## Design Process




Given our limited prior knowledge of MR, it became imperative for us to gain firsthand experience with this emerging technology in order to comprehend its functionality and explore its potential applications. To facilitate this process, we used the MRTK (Mixed Reality Toolkit) examples hub. This approach enabled us to develop an understanding of MR technology and served as a steppingstone for further investigations in our research.

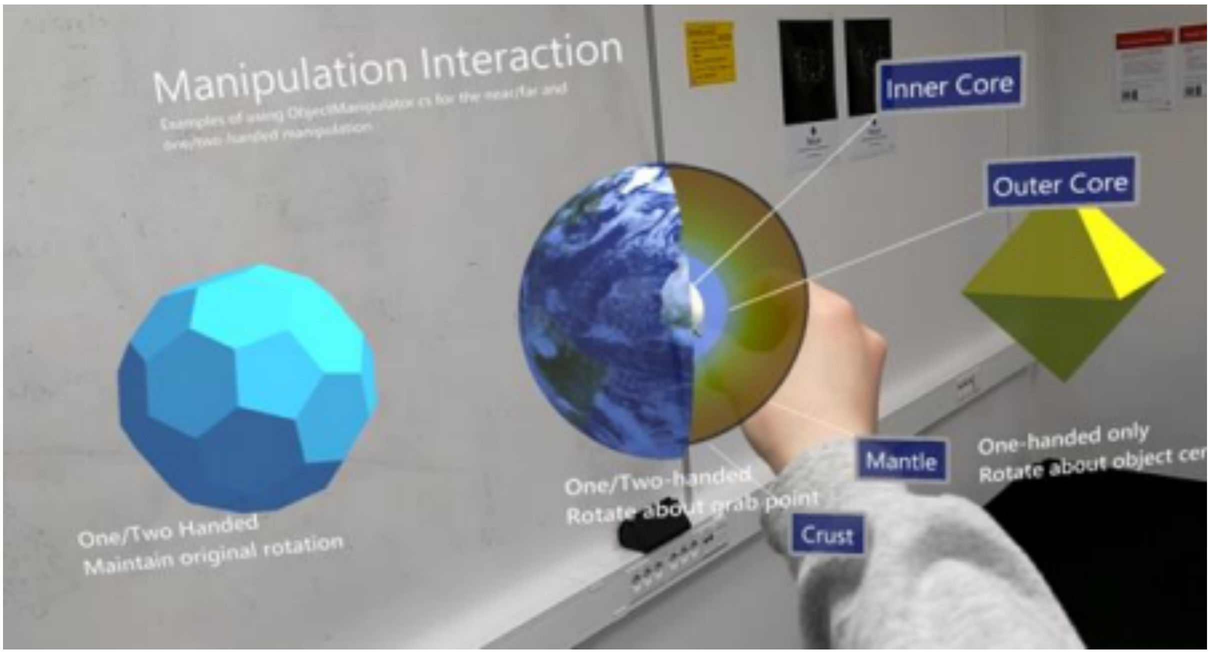



*Figure 10 - Example of 3D models from MRTK examples hub, hand interactions.*

In order to comprehend the capabilities of HL2, we conducted a series of experiments encompassing its potential applications in productivity, gaming, and leisure activities. To assess its productivity features, we substituted a laptop with a mouse and keyboard setup, evaluating the extent to which the HL2 device could facilitate efficient work tasks. In the gaming context, we explored the level of interactivity and immersion it offered to enhance the gaming experience. Furthermore, we investigated the suitability of the HL2 for leisure activities, particularly focusing on news reading, casual browsing, and video watching. In this regard, we examined both near-hand and far-hand interactions. Near-interaction involves physical contact with virtual holograms, while far-interaction allows for remote interaction. For far-interaction, when a hologram was at a specific distance from the hand, white "pointing lines" appear from the tip of the hand, serving as an extension of the hand for interaction. To interact with holograms in far interaction, users have to use a "pinch" gesture by pressing the thumb and index finger together. To click, the user taps the fingers together while keeping them together to grab.

Throughout these experimentation sessions, we gathered valuable insights that guided the development of our prototype, with a specific focus on exploring the benefits of an interactive map that would highlight locations mentioned in articles featuring substantial geographic information.

After extensive brainstorming, sketching, and exploring the HL2 device, we reached the decision to integrate NRK news articles into the HL2 browser. Additionally, we downloaded an interactive map and positioned it adjacent to the news article on the right-hand side. To facilitate ease of comprehension, we included pins on all the locations referenced in the news article. The prototype, showcasing these features, can be observed in Figure 12.

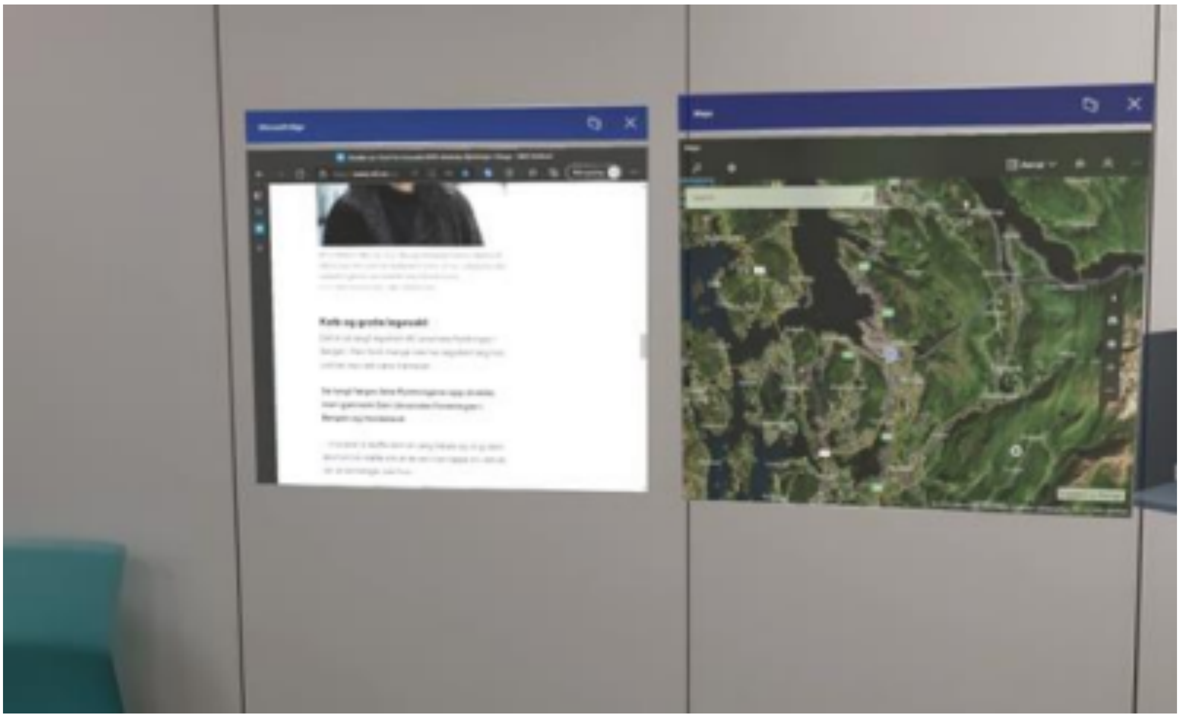
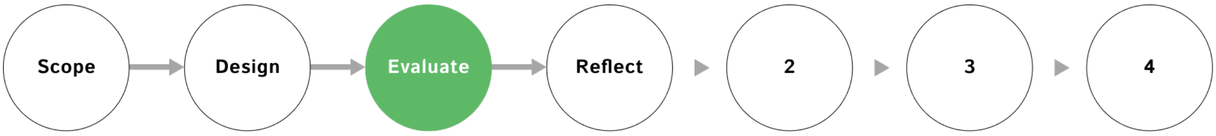


*Figure 11 - Example of the prototype, the article is on the left side and the map on the right.*

## Evaluation

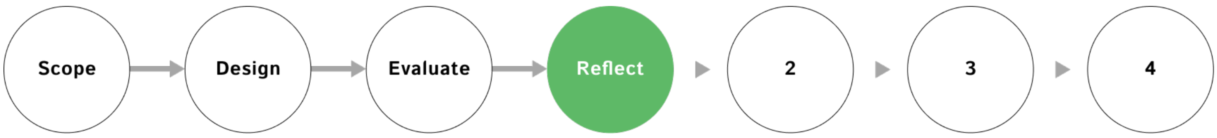



To evaluate the effectiveness of our prototype, we conducted a series of five expert interviews with two distinct target groups. The first group consisted of individuals diagnosed with dyslexia. Since our primary objective was to explore how MR technology could assist individuals with dyslexia, we sought direct insights from potential future users within this group. The second target group encompassed the participants described in the participatory design section, who were selected to provide broader perspectives and input.

To ensure a conducive environment for the interviews, we secured the "Forsknings lab" and "Seminar 2" rooms at Media City Bergen. Prior to the scheduled interviews, we allocated half an hour for preparation to ensure all technical aspects were properly set up. Two roles were designated for the interview process - the lead interviewer and the technical interviewer - with a rotation between the two roles after each interview. The lead interviewer conducted the interviews, while the technical interviewer was responsible for arranging the technical equipment and guiding participants through the user testing phase in the HL2 device.

The interview process was divided into three distinct parts. Firstly, we conducted a background interview to gather relevant information regarding the participants' prior experience with news and XR. Afterward, participants were asked to read a news article on a laptop, which served as a basis for discussion and allowed us to explore their diverse experiences. Following this, a test session in the HL2 was administered, during which participants spent approximately 10 minutes familiarizing themselves with the technology through a semi-guided session in the MRTK examples hub, specifically the hand interaction demonstration. For participants who exhibited hesitation or had not attempted specific interactions, we provided suggestions and guidance. After the familiarization phase, participants tested our prototype by reading the article within the HL2 device. Finally, a semi-structured interview was conducted to gather feedback on their experience, and the data collected was analyzed using thematic analysis methods.

## Reflection




Upon analyzing the interviews, several recurring themes emerged, shedding light on important aspects of the participants' experiences. These themes included learning curve and navigation issues, stress and distraction, map-related challenges, general positive feedback, and user insights regarding future development.

All participants were novice users with limited or no prior experience with XR technologies in general. They highlighted the initial adjustment period required to become accustomed to the HL2 device, given its significant divergence from their daily technological interactions. However, some participants expressed optimism that with time and familiarity, they would become proficient in navigating the technology, ultimately leading to an improved user experience. Moreover, it was noted that a learning curve is expected with any new technology, and this should not be perceived solely as a negative aspect.

Navigation in the HL2 posed challenges for all participants, primarily due to technical limitations coupled with their lack of familiarity with the device. Familiarizing themselves with the various hand gestures required time and practice, as participants often needed to exaggerate their movements for the HL2 to register them accurately. This led to instances where participants unintentionally performed gestures, causing the device to register actions that were not intended. Additionally, participants encountered situations where the HL2 interpreted gestures differently from their intended actions, preventing them from achieving the desired outcome.

The navigation difficulties experienced by participants proved to be highly distracting. Some participants expressed a degree of anxiety, fearing that excessive interaction might lead to errors. Furthermore, four participants encountered issues related to scrolling within the article, with the page continuously scrolling or unintentionally highlighting text. These challenges resulted from the HL2's failure to register the release of a pinch gesture or unintentional double-tapping. Participants also found the scrolling process physically straining, and some mentioned difficulties in reading the text on the screen, which contributed to increased distraction. Participants expressed concerns about the format of the article, stating that utilizing the same format as on a laptop led to unfamiliar navigation methods and added noise and distractions. Overall, participants emphasized the need for improved navigation to enhance the user experience.

Despite the challenges encountered, participants generally acknowledged the positive impact of the map feature. They found it useful for visualizing the article's content, enhancing immersion. However, participants also faced issues with the map, similar to those experienced with the browser, as it was designed for laptops and not optimized for the interactive nature of the HL2. Participants highlighted difficulties related to small buttons and markers, accidental touch-triggering of pop-ups, and a lack of connection between the map and the article. Some participants even overlooked the map entirely, as their focus remained solely on scrolling through the article.

Participants provided numerous suggestions for improving the user experience in future developments, particularly addressing the technical limitations of the HL2. These suggestions included enhancing hand gesture recognition, making gestures more distinguishable, improving the Field Of View (FOV) for better visibility, and developing a more compact headset. While certain limitations could not be directly resolved, these insights provided valuable guidance for potential solutions in future iterations. Participants also emphasized the importance of legibility and dynamic interactions between the map and the article's content. They expressed a desire for news articles to be better tailored to the platform.

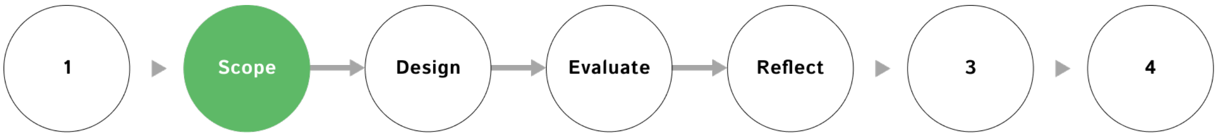
Our observations revealed that the browser in the HL2 device posed significant challenges for participants when it came to interaction. Its design, which was originally intended for laptop/desktop use, proved to be poorly suited for HL2. Therefore, many design choices failed to accommodate the interactive nature of the HL2's interaction methods. This mismatch between the browser's design and the HL2's capabilities hindered participants' ability to navigate and interact with the system effectively. It became evident that participants would be more inclined to utilize a system that featured better adaptation to the HL2 platform, offering seamless usability with minimal physical strain.

Furthermore, we noted that visual displays, particularly the interactive map, played an important role in enhancing the user experience. The majority of participants expressed that the presence of the map facilitated their comprehension of the accompanying text. By visually connecting geographical locations mentioned in the article, the map contributed to a better understanding of the contextual information. However, it is worth noting that improvements can be made to enhance the connection between the map and the storytelling in the article, warranting consideration in future developments.

## Iteration 2

In this iteration, a total of three design workshops were conducted to prototype. In the initial workshop (W1), only Fay and I participated as the sole attendees. Subsequently, the second workshop (W2) and the third workshop (W3) were carried out with valuable contribution of domain experts. Specifically, W2 involved the participation of three IT experts, while W3 benefited from the insights and expertise of four interaction design experts.

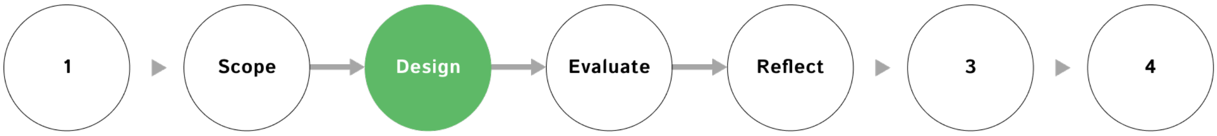
### Scope




The primary objective of this iteration entails exploring diverse design alternatives and determining the elements to be incorporated while developing a prototype through the utilization of Unity. To confine the scope of this phase, we conducted a retrospective analysis of our reflections from iteration 1. Since users demonstrated a favorable response towards the map and acknowledged the utility of visual displays, our focus is on investigating methods to enhance the integration of the map within the storytelling aspect of the article. Moreover, we aim to ascertain how the map can be designed to amplify immersion and engagement.

Additionally, we aim to identify other visual displays that may offer advantages and explore effective presentation techniques. Furthermore, we seek to explore possibilities concerning navigation and interaction and define appropriate implementation strategies. To accomplish these objectives, we collaborated with IT and interaction design experts in a series of design workshops. During these sessions, we engaged in design activities employing traditional pen and paper approaches to outline and deliberate potential solutions.

## Design Process




The progression involved the organization of three sequential workshops denoted as W1, W2, and W3, wherein design activities were executed through the medium of paper sketches. These workshops aimed to cultivate concrete ideas that could be thoroughly deliberated and considered for the subsequent advancement of the prototype.

W1 was exclusively conducted by Fay and myself, motivated by two primary reasons. Firstly, we sought to establish our individual thoughts and ideas pertaining to the system's potential inclusions and visual representation. Furthermore, this exclusivity enabled us to establish a mutual understanding and consensus on the system's envisioned characteristics, as well as contemplate potential solutions. This preliminary workshop served as a foundation to better equip us for incorporating additional participants in subsequent workshops. Secondly, we aimed to gain firsthand experience of the design activities that would be undertaken with the workshop participants. Through testing these activities ourselves, we had the opportunity to assess their effectiveness and make necessary adjustments beforehand. During W1, two exercises were carried out. Initially, we engaged in a ten-minute session of individual sketching, where we rapidly translated our visualization ideas for the article's design onto paper, focusing on capturing concepts rather than intricate details. Subsequently, we expounded upon and discussed our respective concepts, leading to the second exercise, which involved reaching a consensus on the crucial features to be prioritized in the subsequent development stages of the prototype.

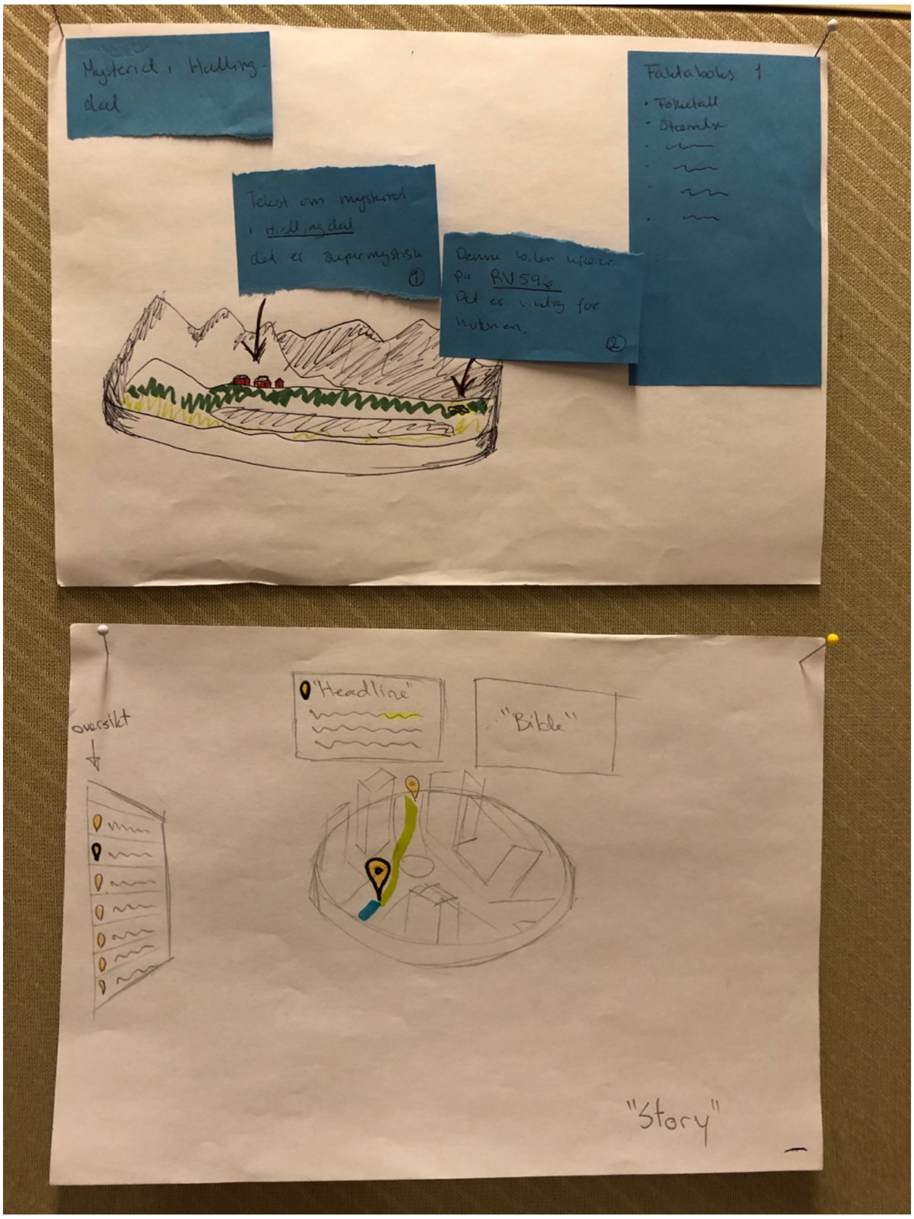



*Figure 12 - Sketches made by Fay (top) and me (bottom) in W1.*

During W2, three IT professionals working in the IT department at UiB actively participated, while W3 involved the engagement of four master's students specializing in media and interaction design. The primary objective of the initial design activity was for the participants to visually articulate their envisioned presentation of the article within HL2, aiming to enhance comprehension. Each participant was allocated ten minutes to sketch their concept design, followed by an explanation of their respective designs.

Subsequently, extensive discussions were conducted to explore the diverse solutions proposed by the participants, with a specific focus on combining the most promising ideas into a unified concept.

Two examples of the sketches generated by the participants in W2 and W3 are visually documented in Figure 14. A majority of the concept ideas revolved around the incorporation of some form of map representation. These ranged from 2D maps, 3D maps, and globes in varying orientations, with most including map markers. These map-centric designs were generally complemented by additional elements such as text boxes, images, 360-degree scene views, metadata boxes, figures, and interactive objects. For instance, an example depicted in Figure 14 showcased a thermometer that illustrated the current state of a river in terms of temperature. Users could adjust the thermometer to explore how the river appeared in the past with lower temperatures, as well as project future scenarios with increased temperatures. Various interaction modalities were also proposed, including hand gestures, eye-gaze tracking, and speech interaction.

In the subsequent task, participants engaged in a comprehensive discussion on how to combine the most favorable features from their individual designs into a single solution. The suggested solution entailed the inclusion of a textual screen presenting the article content, accompanied by a horizontally positioned interactive 3D map. This map would dynamically display narrative elements, such as floods or droughts in rivers, through engaging animations. Users would have control over the animations by utilizing a slider, enabling them to observe the effects over time and adjust the pacing. The map should inherently possess interactivity, while simultaneously aligning with the progress and storyline of the article. Supplementary information would be accessible through metadata boxes, facilitating further exploration. Additionally, the article would incorporate images, videos, and animations to immerse users and provide visualizations of the map elements and corresponding textual content.

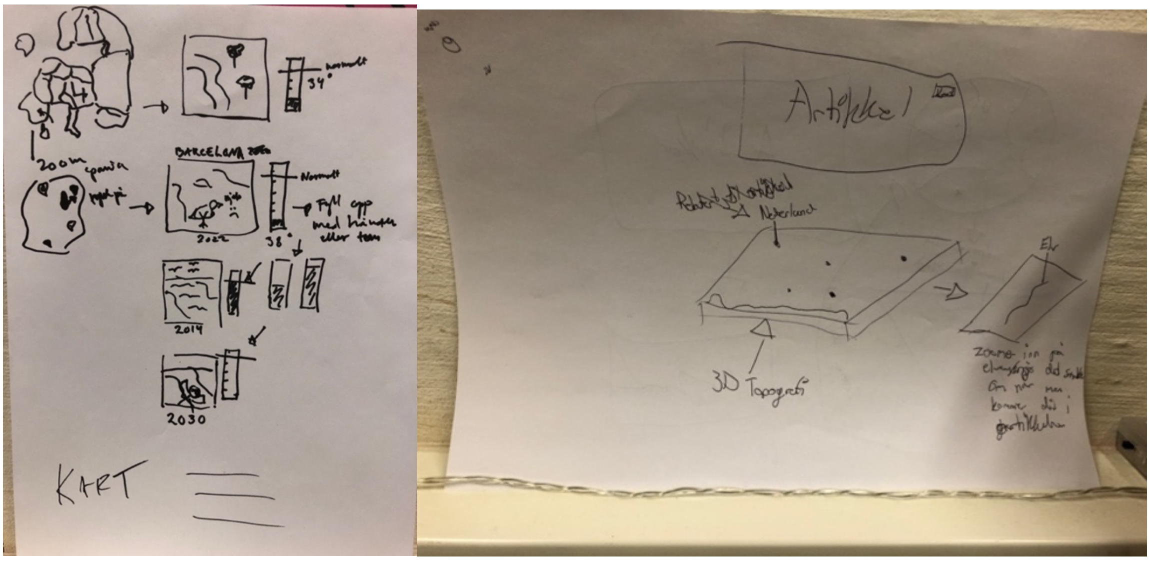



*Figure 13 - Examples of sketches from participants in the first exercise.*

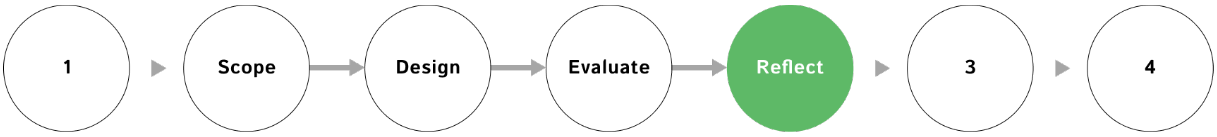
## Evaluation


The organization of the workshops followed a structured framework encompassing three distinct parts. Part one entailed an introductory session aimed at familiarizing the participants with the problem space and HL2. Considerable time was dedicated to explaining the underlying technology, providing the participants with a comprehensive understanding of the design possibilities inherent to the medium and its interactive nature.

In part two, participants were presented with a news article, which they read either on a laptop or a smartphone. The selected article focused on the ramifications of climate change and encompassed numerous geographical references and visual elements, such as images. This deliberate choice aimed to encourage the participants to contemplate design considerations specific to news articles that incorporate substantial geographic information. By providing a shared scenario, participants were able to align their thinking and generate design choices pertinent to this context.

The third and final part encompassed the sharing our initial concepts and sketches, followed by a collaborative discussion with the participants. During this discussion, concepts were compared, and a collective understanding of the desired features, presentation methods, and crucial considerations for such systems was developed. Subsequently, the gathered data underwent thematic analysis to extract meaningful insights and patterns.

## Reflection




Upon conducting an analysis of the workshops, several recurring themes emerged, namely the nature of news consumption, interactive exploration, and accessibility.

The nature of news consumption refers to how individuals prefer to consume news content. Our findings indicated that our target demographic of young adults seeks quick information acquisition, often limited to reading headlines, particularly when accessing news on mobile devices, which is frequent in their daily lives. Additionally, we discovered that some avid news readers appreciate the in-depth experience and knowledge gained from reading traditional newspapers, as well as the comprehensive overview facilitated by this format. However, they noted that they rarely have the time to engage in such reading during busy weekdays.

When creating news pieces for HL2, it is crucial to consider the preferences of the majority of readers who prefer simple and quick news consumption. "Simple" implies that the content should be easily digestible without necessitating complex interactions or movements. Simultaneously, "quick" indicates that readers should be able to grasp the essence of an article without having to read it in its entirety. However, it should be emphasized that depending on the media or technology utilized, a person's preferred method of news consumption may vary. While some readers may become accustomed to consuming news articles with intricate interactions, others may prefer traditional news consumption. Therefore, the question arises as to whether readers are willing to invest more time in articles that demand greater effort or if they prefer a fast-paced, low-effort news consumption experience.

The majority of participants expressed a desire for interactive elements to be incorporated into the concept, as it enhances the immersive experience. Furthermore, storytelling opportunities using interactive objects were recognized, exemplified by the inclusion of a thermostat in one participant's sketch, which vividly demonstrated the impact of a few degrees on rivers. Most participants also conceptualized interactive maps that illustrated the potential for exploration. In both W2 and W3, the concept of exploration was mentioned multiple times, signifying the readers' desire to delve deeper into subjects of interest and access metadata related to topics discussed in the article.

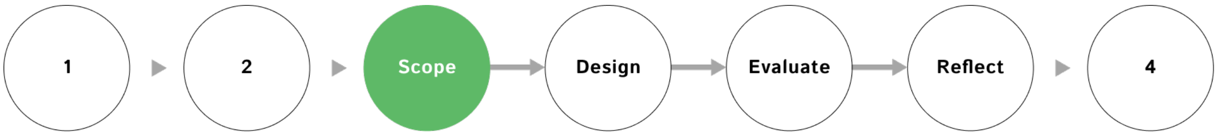
Regarding accessibility, participants explored alternative interaction methods, such as text-to-speech functionality, which would allow the article to be read aloud. This feature would enable users to multitask while consuming news content. Additionally, this would free users from focusing on the text, allowing them to devote attention to other visual displays that support the article.

Participants also raised concerns about the potential impact of excessive interactivity and spatial requirements. If an article becomes too interactive and demands significant physical movement, it could present accessibility challenges for individuals with physical disabilities. Moreover, the user experience would be limited if the article necessitates usage in a large physical space.

## Iteration 3

In the current iteration, a functional prototype of MR news was developed using Unity. To assess the effectiveness and user experience of the prototype, a series of three workshops were conducted, each involving a single participant.

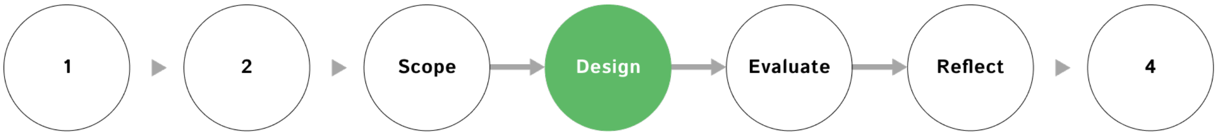
### Scope




The primary objective of this iteration encompassed the development of a fully functional prototype in HL2 using Unity. The decision to utilize Unity was driven by the need to overcome the limitations associated with using a browser and a separate map, as it afforded us greater flexibility in designing our own system. Recognizing the significance of cohesive storytelling, we sought to establish interconnected components within the prototype.

Upon revisiting our insights on news consumption, we acknowledged the importance of ensuring articles are easily comprehensible while enabling readers to explore specific areas of interest in greater depth. However, due to constraints such as limited time, our limited expertise in building HL2 applications, and the absence of pre-existing plugins, we had to scale back some of our more ambitious ideas. Nonetheless, we successfully devised a solution to incorporate the essential concepts from Iteration 2, albeit with reduced fidelity, while maintaining their intended purpose.

## Design Process




Throughout the iterative design process, we conducted thorough reviews of best practices and design principles by consulting Microsoft HL2 documentation, as well as resources on accessibility and design in Extended Reality (XR). Additionally, we explored alternative development tools such as Aero, Unreal Engine, and Blender for animation purposes. Ultimately, we made the decision to continue utilizing Unity due to the potential restrictions imposed by applications like Aero, and the impracticality of switching to Unreal Engine after investing significant effort in becoming acquainted with Unity. Moreover, we found that creating animated components in Blender was too demanding and time-consuming, leading us to refrain from using it.

In our quest for suitable prefabs and map integrations, we examined options like HoloMaps by Taqtile, which aligned with our envisioned requirements. However, after several attempts, we discovered that most prefabs did not align with our prototype's specifications, as there are currently limited prefabs available that are compatible with the Mixed Reality Toolkit (MRTK). We reached out to Taqtile with hopes of building our solution on their 3D map. Unfortunately, they encountered funding issues that resulted in significant map-related difficulties, rendering it impossible for us to incorporate their map into our project. We then explored the possibility of creating our own interactive 3D map integration using datasets from Google Maps. Although this approach held promise, we decided against pursuing it due to the considerable time investment required and the absence of guarantee for success or viability. Consequently, due to these limitations, we redirected our efforts towards enhancing our proficiency in Unity and exploring the possibilities of creating our desired components independently.

With a realistic understanding of what was achievable within the given timeframe for the working prototype, we commenced the process of sketching our ideas for the setup using

Figma. To prioritize the creation of a Minimum Viable Product (MVP), we opted for simplicity in our chosen components. Specifically, we selected a VG article on the correlation between global warming and increased occurrences of extreme weather conditions worldwide. The identified components for inclusion in the prototype encompass a central text box screen, a menu screen positioned on the left side, an image screen on the right side, and a tilted map screen along with a metadata screen below. Additionally, the article's headline would be positioned above the text box screen without a separate screen or background. A visual representation of the sketch can be seen in Figure 15.


*Figure 14 - Figma sketch of the prototype layout.*

Once we had a well-defined plan for the article's content and design, we started developing the prototype in Unity. The text screen took center stage as the primary component, with the other supporting components strategically positioned around it. To ensure a seamless reading experience, we concealed the button borders to prevent interference with the text.

The back button occupied one-third of the left side of the screen, while the next button spanned two-thirds of the right side. This size ratio was intentional, considering that the next button would be the most frequently used, and its larger size facilitated easy selection without precise aiming.

To address the challenges some participants faced with scrolling functionality in the initial iteration, we divided the article into a textbox format, or dynamic slideshow. Breaking the article into smaller sections to make it easier for readers to digest the content. Additionally, this division allowed for simple synchronization between the supporting screens and the text. We also incorporated a progress bar on the text screen, enabling users to track their progress within the article.

The menu component consisted of a textbox positioned at the top and buttons corresponding to the sub-headlines in the article. These buttons provided users with a swift means of navigating back and forth within the article by directing them to the first slide of each sub-headline. To indicate the active sub-section, the buttons changed color to white. The progress bar and menu served to offer users an overview of the article's structure and facilitate efficient navigation.

Images within the prototype changed dynamically to correspond with the information displayed on the text screen. Each image was accompanied by descriptive text located directly below it, providing additional context. The metadata component was linked to the text, specifically focusing on the four interviewed scientists in the article. The metadata displayed their names and pictures, changed based on the scientist featured in the current text screen. In future articles, the metadata box could potentially be utilized for other relevant information or supplemented with an additional metadata box on the opposite side of the map.

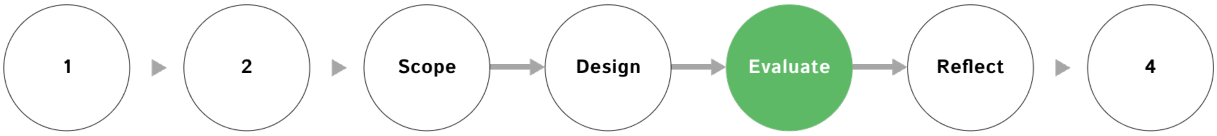
The map component employed a world map that highlighted locations mentioned in the current textbox. However, in this iteration, the map remained non-interactive, with its purpose limited to visual representation of the geographical content in the text.


*Figure 15 - Example of the prototype from Workshop 1.*

Following the first workshop, we introduced a new button positioned above the menu, allowing for scene manipulation when activated. This functionality could toggle on and off, as we encountered challenges in adjusting the sensitivity of scene manipulation. By implementing a toggle mechanism, we aimed to minimize user errors associated with this feature, intending to refine and improve it in subsequent iterations if required.

Furthermore, prior to the second workshop, we made modifications to enhance readability. Specifically, we changed the color scheme of the text screen to white and adjusted the text color to black. This alteration aimed to determine whether a white-on-dark or dark-on-white color combination offered better readability for participants.

## Evaluation




To evaluate the prototype, we conducted a series of three workshops, each involving a single participant. This approach was chosen to provide participants with firsthand experience of HL2, allowing them to become acquainted with the medium and test the prototype. The workshops aimed to facilitate discussions on the user experience and identify potential areas for improvement in the fourth iteration.

The decision to have only one participant per workshop was primarily due to the limitation of having only one HL2 device available. Including additional participants would have necessitated significant waiting times of approximately twenty to thirty minutes per additional participant. Considering that HL2 is a relatively new medium for the participants, delays could lead to discomfort and a rushed approach, potentially affecting the quality of the data collected.

Each workshop had a duration of approximately one hour, although some sessions extended slightly beyond the allocated time.

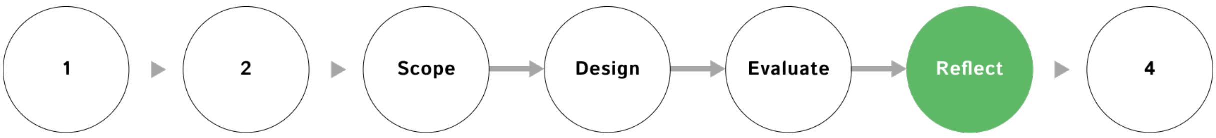
The workshops were structured into three distinct parts. The initial segment included a brief introduction to the prototype, its purpose, and an overview of the workshop agenda. Additionally, a background interview was conducted to assess the participants' familiarity with XR and MR technologies, as well as their news consumption habits.

The second part of the workshop centered around HL2. Participants were initially provided with around ten minutes to explore the MRTK examples hub, specifically focusing on hand interactions to familiarize themselves with the HL2 environment. Afterwards, they engaged with and explored the prototype we had developed.

The final part consisted of a semi-structured interview and discussion, where participants shared their impressions of the prototype, discussed their experience using it, and provided suggestions for potential improvements. The data collected during these discussions would then be subjected to thematic analysis for further analysis and interpretation.

*Figure 16 - Example of the prototype from Workshop 2.*

## Reflection




During the evaluation of the prototype, several key themes emerged: readability, navigation, and issues regarding the visual displays. Readability focused on the participants' perception of the reading experience and potential improvements. It encompassed their experience with reading the text in the article and suggestions for enhancing the reading experience. Navigation referred to the users' interaction with the article, their struggles, and ideas for improving the interactions. Visual displays encompassed standalone components such as the map, metadata, and progress bar within the article.

The participants encountered difficulties with readability, particularly when attempting to observe all objects simultaneously within the scene. One participant attributed these challenges to hardware limitations, such as a FOV, low resolution, and blurry color representation. To address the limited FOV, participants scaled down the scene. However, they found that the text on the text screen became too small and lacked clarity, requiring significant concentration to read. Some participants suggested implementing an adjustable text size feature to address this issue. Both color combinations, white on dark and dark on white, posed challenges for readability.

The participants appreciated the immersive and interactive reading experience offered by HL2, noting increased engagement leading to improved memory retention, comprehension, and focus. However, the initial lack of object manipulation capabilities in the scene frustrated one participant, who desired the ability to scale and move the scene for better positioning. Additionally, participants expressed the need to enlarge the scene for improved readability without straining their eyes. Because they were new users, participants faced challenges in navigating the technology, primarily due to the learning curve and hardware limitations. Gestures, particularly exaggerated motions for selection and pinching, proved difficult to master. Participants found scene manipulation too sensitive and prone to errors, resulting in limited use. To address navigation issues, the implementation of on-click interaction was introduced based on feedback from the first iteration, which significantly improved user experience. Participants expressed interest in alternative navigation methods such as voice commands and head or gaze tracking.

One participant suggested aligning the menu horizontally to maintain consistency in text flow. The placement of arrows for moving between textboxes caused distractions and misunderstandings, with participants struggling to aim at them and sometimes misinterpreting their function due to unclear button size.

The map was deemed useful by participants, aiding orientation and helping them remain engaged. Participants expressed a desire for interactive features, such as zooming in on the map when locations are mentioned, as well as the ability to explore and obtain more information about selected locations and subjects. Participants also suggested receiving notifications when changes occurred in the map and other visual displays, as they found it challenging to keep all screens within their field of view while reading comfortably or navigating.

Regarding the metadata screen, participants had similar comments as with the map, desiring feedback when the screen changed and requesting additional information beyond displaying only the image and name of the mentioned scientists.

The progress bar concept received positive feedback from all participants as a means of staying updated and oriented. However, they provided suggestions for improvement. One participant felt demotivated by the numeration below the progress bar, perceiving it as indicating a lengthy process. Another participant suggested making the progress bar interactive and found the current menu imprecise. They drew comparisons to e-books and PDFs, where mini page previews offer easy navigation and orientation, proposing similar adaptations for the prototype.

### Iteration 4

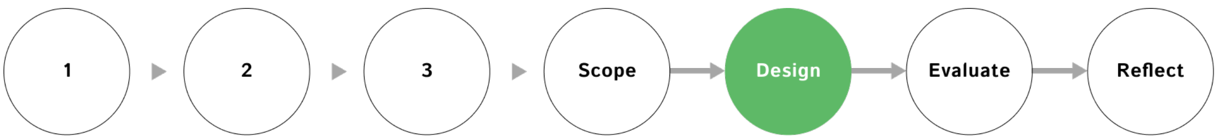
In the fourth and final iteration improvements were made to the design and navigation before the prototype was evaluated through a series of seven workshops.

## Scope


As this final iteration approached, a review of my research question (RQ) and a consideration of the desired changes became necessary. To define the problem space, I analyzed the field reports from past iterations. It became apparent that the integration of visual structure and navigation was crucial in adapting news articles to MR environments, while users expressed a desire for visual storytelling complemented by interactive maps.

To initiate the design process, a collaborative workshop was organized between Fay and myself, allowing us to sketch out and deliberate on various design concepts for the prototype before executing the design in a Unity prototype. In order to assess the effectiveness of the prototype, workshops were conducted with users from the target group.

## Design Process




Prior to commencing any design-related tasks, an extensive literature review was undertaken to gain insights into best practices, accessibility considerations, and design decisions outlined in Microsoft HL2 documentation, building upon the findings from the third iteration. The documentation comprehensively addresses several pain points highlighted by the participants in the previous iteration. For instance, it recommends employing specific color schemes, such as white on blue, to mitigate the limitations of HL2's low resolution and enhance readability (Microsoft, 2023). Consequently, we made design choices aligned with the recommendations in Microsoft's documentation to address the issues encountered by the participants in the previous iteration.

To establish a clear direction for the prototype's design based on our research findings, a design workshop was conducted. The workshop served as a platform for discussing and refining the design concepts. Various design activities were undertaken during the workshop, each focusing on different aspects of the prototype. These activities involved sketching on paper, accompanied by brief explanations, with each activity lasting approximately ten minutes. Following the completion of each activity, the ideas were presented, and in-depth discussions were held to further refine them. The workshop commenced by determining the screens and features to be included in the prototype, followed by individual consideration of each component. Finally, all the agreed-upon ideas were combined into a coherent design.

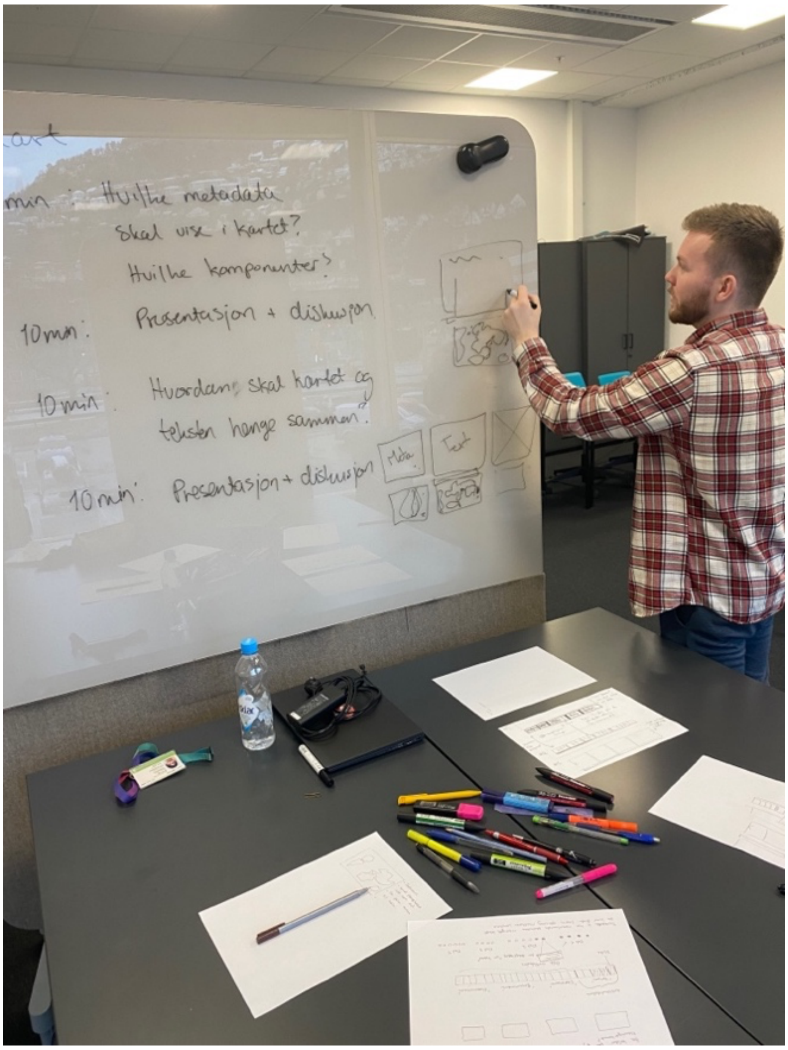



*Figure 17 - Image from the design workshop.*

To address some of the issues identified in the third iteration of the prototype, such as limited FOV, physical strain, and navigating while simultaneously viewing all screens, our focus shifted towards leveraging far interaction. By emphasizing far-interaction, we aimed to address these challenges, as it offers greater flexibility in scaling and reduces physical strain. Additionally, we sought to enhance the customization of the article by enabling users to manipulate individual screens and the entire scene. Simultaneously, we improved the manipulation interaction through the implementation of a script that reduced interaction sensitivity and restricted screen rotation in specific directions to maintain their alignment. To enhance usability, we eliminated the toggle button, which proved inconvenient for users, and introduced top bars for all screens. Users can now manipulate screens by grabbing their respective top bars. Placing the title in a top bar positioned above the article allows users to manipulate the entire scene. This design choice aims to separate functionality from the screen content, enabling users to touch the screens without inadvertently triggering manipulation. This approach aligns with the current standard in HL2 screens.

Furthermore, interactive elements were incorporated into the map, providing users with the opportunity to access additional information about specific locations impacted by events mentioned in the article. To accommodate this functionality, a new screen was added, featuring text, pictures, or illustrations to convey relevant details. The design of the prototype is visually depicted in Figure 19.

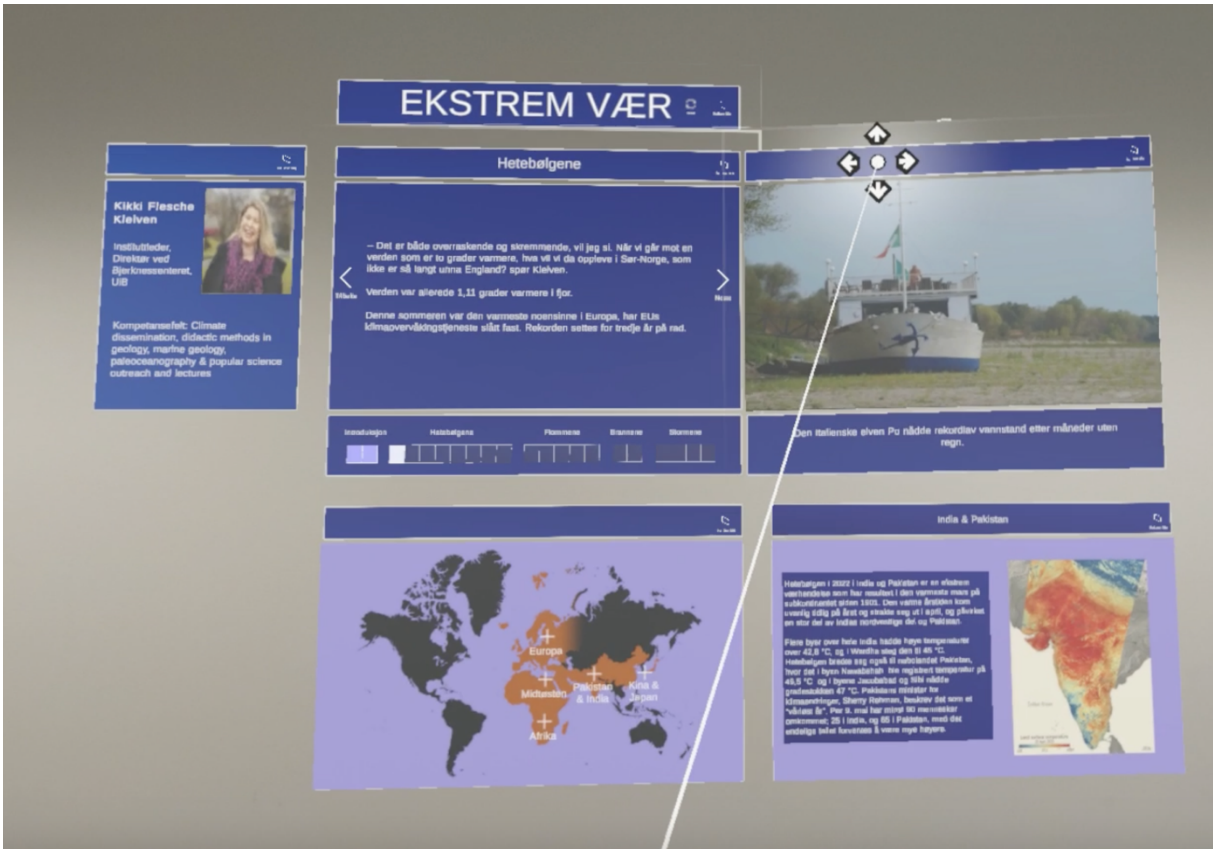
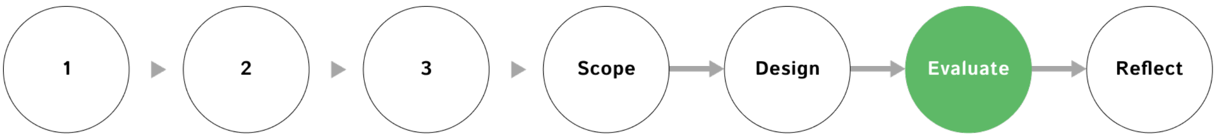



*Figure 18 - Example of moving individual screens in the prototype.*

## Evaluation



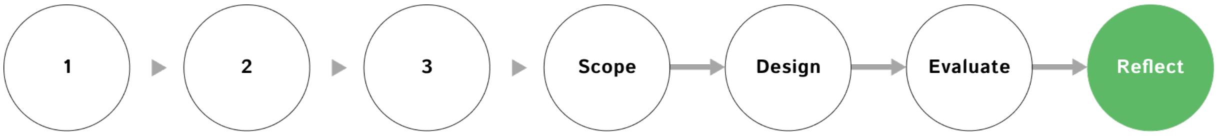

We conducted a series of seven evaluation workshops, each with one participant. Notably, all three participants from the third iteration also participated in this iteration. Prior to the evaluations, we provided a brief introduction to our projects and presented the prototype to the participants. The evaluation process encompassed three distinct parts.

The first part consisted of a short interview aimed at gaining insights into the participants' news consumption habits and their familiarity with XR and MR technologies.

In the second part, participants engaged with HL2, starting with familiarizing themselves with gestures through the use of MRTK examples hub, hand interactions. We specifically focused on teaching them how to utilize far-interaction and manipulate objects similar to those in the prototype. Our objective was to ensure that participants were comfortable and acquainted with the necessary gestures before proceeding. On average, this familiarization process took approximately ten minutes. Subsequently, participants were assigned tasks. During these tasks, we encouraged participants to vocalize their thoughts, known as "thinking out loud," sharing their observations, struggles, preferences, and any other feedback related to the prototype. This approach allowed us to capture their initial and evolving thoughts on the prototype. The first task involved reading and exploring the article, while the second task entailed adjusting the layout to their preferences, including scaling, moving, and tilting the components, accompanied by explanations for their choices. Following this, we presented two alternative layouts that we had designed to stimulate discussion regarding the pros and cons of the four layouts: the original, participant-modified, and the two alternatives we proposed. Additionally, we individually assessed each component of the prototype with the participants, seeking insights into how they influenced the overall user experience. Participants were then asked to rate the components and provide feedback on any missing or redundant elements.

In the third and final part of the evaluation, participants were asked to self-assess their experience in reading an article in this format, including their level of retention. Furthermore, we engaged in a discussion focused on the user experience, exploring topics such as their thoughts on having all the content readily available and their experiences with the interactive nature of the medium.

## Reflection




Through our analysis, we have identified recurring main themes in our study, namely Ease of Use, Interactivity and Accessibility, Focus and Orientation, and Personalization.

The theme of Ease of Use can be divided into three categories: Learning Curve, System Acceptance, and Technology Acceptance. Learning curve refers to the participants' initial struggles in adapting to the new technology, including unfamiliar navigation and interface. Technology acceptance measures the participants' overall experience with the technology, specifically the MR system as a whole and the HL2 device. System acceptance focuses on the participant's experience with the prototype we created.

Our findings indicate that all participants encountered a steep learning curve due to the novelty of the technology and unfamiliar navigation. However, with some trial and error, they were able to adapt and learn quickly. Navigation was a common challenge, with participants accidentally clicking and experiencing difficulty in navigation gestures. Nonetheless, some participants found it surprisingly easy to learn. Notably, participants who had previous experience with HL2 in the third iteration were more comfortable, experienced fewer challenges, and easily corrected any errors. They also mentioned that the navigation in this prototype was significantly better and easier compared to the third iteration.

Participants expressed excitement and enthusiasm for the technology, particularly appreciating the situational awareness provided by HL2 and MR. They considered MR to be more appealing than virtual reality (VR) as it offers more casual immersive experiences and the potential to become a part of everyday life beyond gaming. However, the participants mentioned hardware limitations of HL2, such as the bulky headset, narrow FOV, low resolution, and accuracy issues in registering gestures as hindrances for regular use.

Regarding accessibility, categories that emerged include readability, physical strain, alternative navigation, and system feedback. Participants provided feedback on readability, emphasizing that the text size was consistently too small. Although the prototype allowed scaling of the scene and individual screens, the narrow FOV of HL2 made it challenging to see all screens simultaneously, affecting text size. Participants suggested increasing the default text size or implementing a manual text sizing function. However, these solutions present design trade-offs, such as fitting less text on each screen or requiring scrolling or additional space for upscaling. Other accessibility suggestions included voice commands, text-to-speech, and eye-gaze interaction, but participants expressed a desire to keep using hand interaction.

Participants also desired more system feedback, suggesting the inclusion of "on-hover" effects for buttons to indicate selection without obstructing the text on the screen. They mentioned difficulties in maintaining focus due to the limited FOV and the need to constantly look around at each screen for changes. To address this, participants suggested increasing the text size or the relative size of the text screen to allow a greater distance from the scene. Several participants noted that constantly shifting their gaze between the screens became physically straining to their necks. They also expressed interest in receiving notifications when changes occurred.

In terms of the map, participants found it helpful for maintaining orientation and requested more frequent updates synchronized with the text. However, they also expressed a desire for the map to play a more prominent role in the storytelling process and be updated more frequently alongside the text. Some participants preferred a tilted map to enhance the authenticity of an actual map, while others suggested a flat map surface if not for the FOV limitations. Participants valued personalization options, allowing them to optimize the setup based on their preferences and focus on specific screens. They varied in their preferences for different screens, with the text screen consistently considered important, and opinions on other screens such as picture and map metadata varying.

When participants were requested to propose improvements to the scene layout according to their own preferences. The majority of the participants only made minor adjustments, such as changing sizes and tilting screens, without significantly altering the overall layout flow. Many participants expressed that they felt the existing layout was already natural. Nonetheless, when we presented some layout options that we had created, most participants found the first layout option (LO1) to be somewhat better (see Figure 19). In LO1, the 3D space was utilized more effectively, with the picture scaled up and placed in the background. The text screen size was approximately doubled, and the map and map metadata were positioned on the right side, where the picture was originally located in the layout. The participants particularly appreciated LO1 because it made it much easier to view the scene within the FOV due to the increased size of the text screen. Additionally, the picture had a greater impact, enhancing the immersive experience. Moreover, participants found it possible to perceive the mood of the picture without explicitly focusing on it, solely by having it within their peripheral view. Some comments were made about the map, mentioning that it felt less significant and slightly more difficult to see and interact with. However, others mentioned that they did not encounter any issues, especially considering the simplicity of the map in this prototype. One advantage of placing the map beside the text screen, rather than below it, is that the FOV in HL2 is better suited for horizontal rather than vertical viewing. Interestingly, all participants rated LO2 as the least preferable alternative. In LO2, the map is positioned in the background next to the picture, and the map metadata is placed beside the textbox. The reason for the participants' dissatisfaction with LO2 was that including the map in the background somewhat diminished the immersive effect of the picture and made interacting with the map more challenging. Furthermore, they mentioned that LO2 felt more disorganized and lacked a natural flow.

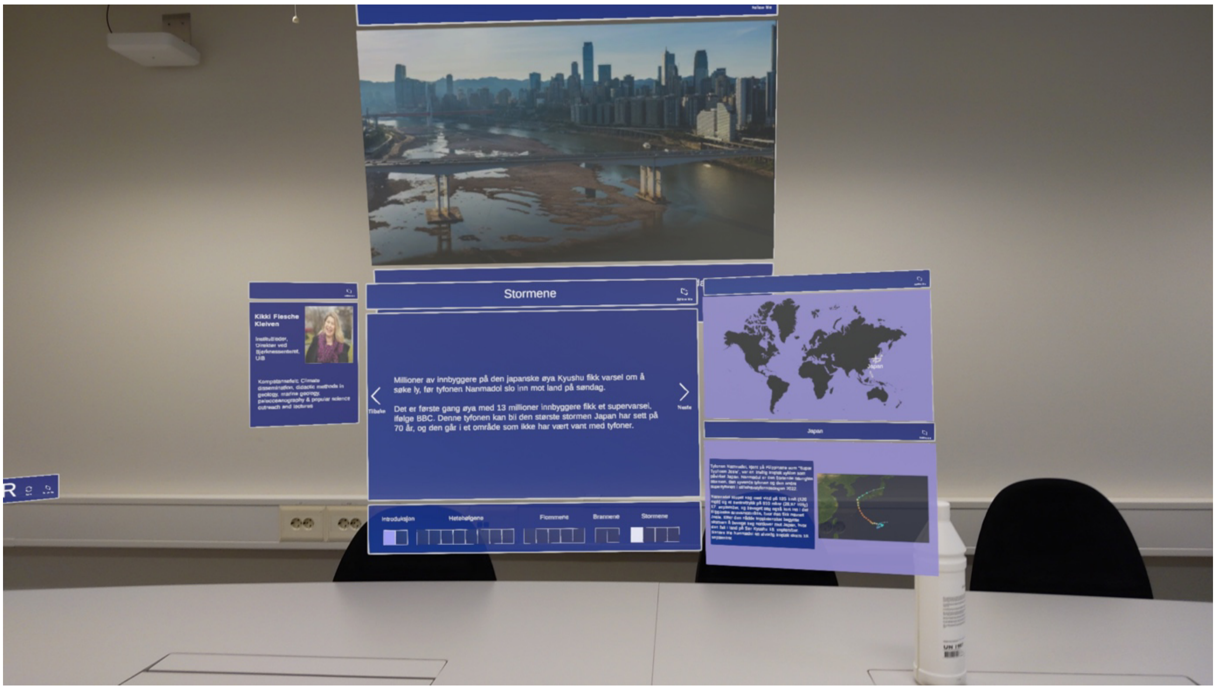



*Figure 19 - Example of layout option 1.*

## MR news

MR news (Figure 21) is the resulting prototype of the prototyping process described above. This prototype serves as a demonstration of how a news article, particularly one encompassing multiple geographical locations, can be adapted for MR experiences. The development of MR news involved the utilization of Unity and the Mixed Reality Tool Kit (MRTK), a Microsoft framework specifically designed for creating MR applications for HL2. MRTK provides prefabs of commonly used HL2 components and behavior scripts, streamlining the software development process.

The interface of MR news consists of several components, with the primary ones being a text screen accompanied by a progress bar directly beneath it, a picture screen, a text-metadata screen, an interactive map screen, and a map-metadata screen. All these different components are continuously displayed, enabling readers to access additional information as needed. Each screen includes a top bar, which allows users to manipulate individual screens according to their preferences. The title bar, situated above the screens, serves as a top bar for the entire setup, facilitating simultaneous manipulation of all components. Users can move, scale, and rotate the screens both horizontally and vertically. Additionally, all the top bars incorporate a follow function, enabling users to select specific screens or all screens to be visible in any orientation. The title bar also includes a reset button, which conveniently resets the layout, offering a "fresh start" with minimal effort. The prototype is intended for use with far-interaction, as it allows for more content within the FOV, and far-interaction is less physically demanding than near-interaction.

The MR news prototype employs a dynamic slideshow as a visual storytelling genre, ensuring linear progression through a sequence of slides. The article text is presented on the text screen to enhance focus on one small section of text at a time. This approach also facilitates the connection between visible elements and the corresponding text. The text-metadata, picture, and map dynamically change as users navigate through the prototype. The picture changes with each slide, the text-metadata changes when different individuals speak, and the map changes for each new sub-headline. Navigation through the text can be accomplished by clicking on the text screen (with a back button occupying 1/3 of the left screen and a next button occupying 2/3 of the right screen) or by using the progress bar. The progress bar provides users with an overview of the article and enables them to navigate through it. Each square on the progress bar functions as a button that leads to a specific screen in the text. These buttons are grouped according to the article's sub-headlines, resulting in the progress bar comprising five smaller progress bars. Hovering over a button provides users with a preview of the corresponding screen. A light blue color indicates that a screen has been read, while a white button signifies the currently displayed screen, and a dark blue color indicates an unread screen.

The map maintains a consistent orientation throughout the experience to provide readers with a continuous overview. However, the highlighted areas and buttons on the map change for each sub-headline. When the article focuses on heat waves, the map highlights the affected locations, and buttons appear. By pressing these buttons, readers can update the map-metadata screen with information pertaining to the selected area and how it has been impacted by the heat waves described in the article. The map-metadata screen comprises a text box containing relevant information and a picture or figure that further illustrates the situation.

The picture screen changes with each slide and represent elements mentioned in the current text screen. Accompanying each picture is a descriptive image text that describes the visual content depicted. This feature plays an important role in establishing the contextual backdrop for the ongoing slide.

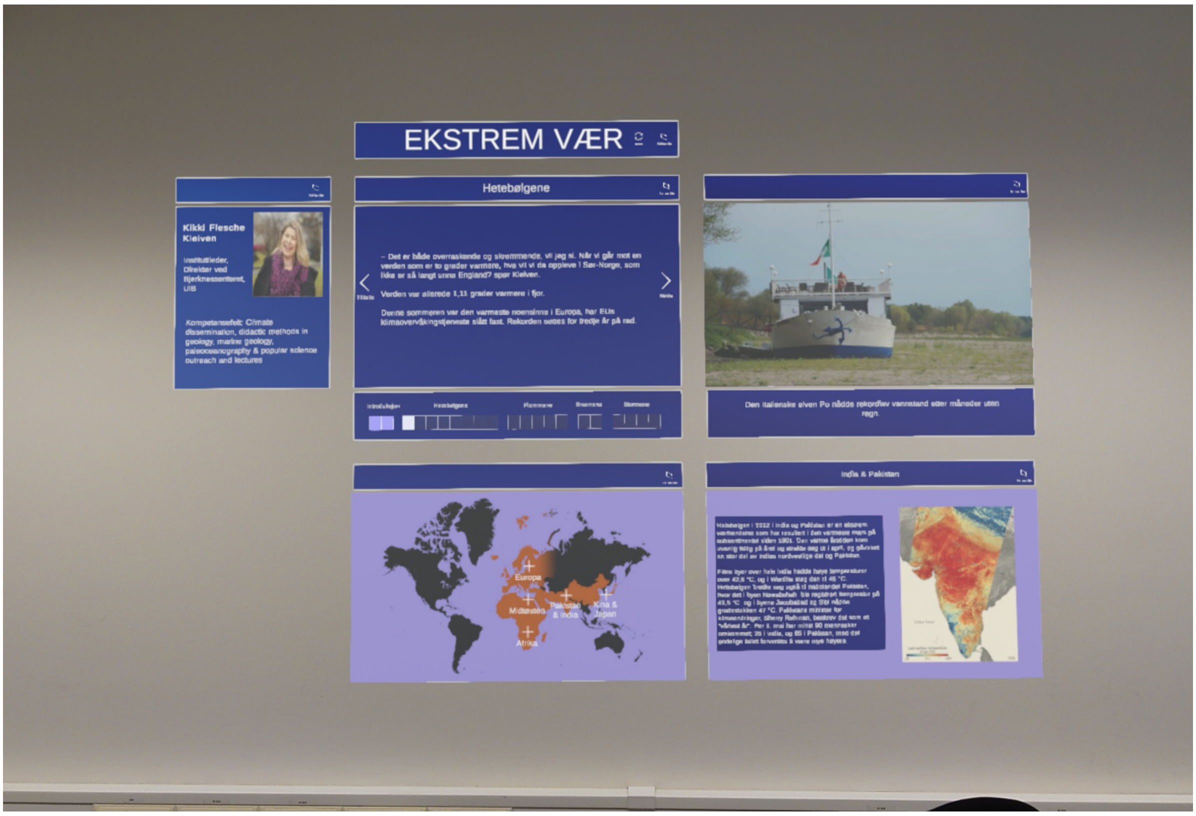



*Figure 21 - Example from MR news prototype.*

# 5. Discussion

To design map-based interactions in Mixed Reality (MR) for visual storytelling, it is important to take into account the concepts of visual storytelling genres and interactive gestures, as these elements play significant roles in the overall design process. Throughout the course of the project, several key findings emerged, which can be considered as categories within these areas. One notable insight is that the principles of storytelling and interaction cannot be directly transferred from traditional PC interfaces to MR Head-Mounted Displays (HMDs), as the interface and interaction differ fundamentally between the two platforms. Moreover, the study revealed that while the map feature proved to be highly valuable for the participants, there exists untapped potential for leveraging its functionality and interactivity to further engage users in the storytelling experience.

## Visual Storytelling Genres

Several approaches can be employed to incorporate visual storytelling with maps in news articles presented in MR, as outlined by Roth (2021). However, the effectiveness of these approaches varies, and combining attributes from different genres while enhancing interactivity could enhance user engagement in MR.

In this research, the initial prototype resembled longform infographics but differed in displaying two screens instead of one. One screen contained the article text and multimedia, while the other showcased a map. Participants found the dynamic scroll interaction to be distracting, leading to numerous errors and demanding excessive focus. Some even forgot to utilize the map until the very end.

During the design workshops in the second iteration, it was discovered that most participants desired 3D maps to play a central role in the narrative. They preferred the map as the focal point, driving the linear storytelling, with text screens appearing to complement the visual storytelling on the map. Throughout the process, several participants expressed interest in seeing graphics and animations incorporated within the map or alongside it, resembling narrated animations. However, participants also desired more interactive animations in addition to narrated ones, which could address some pacing issues encountered in narrated animations. Furthermore, participants expressed a desire for additional information about places and situations through the map. They preferred concise and brief information initially, with options to explore deeper into the details. This could be achieved by linking additional metadata and multimedia, such as narrated animations. By exploiting the 3D space offered in MR interfaces, static visual stories could also be included as metadata features via hyperlinks.

In a study conducted by Song et al. (2022), it was discovered that longform infographics were more effective than dynamic slideshows in terms of user retention. However, our study contradicted this finding.  Song et al. (2022) conducted their research on PC devices, while our investigation used HL2 technology. The familiar format of longform infographics on PCs with vertical scroll interactions may have contributed to higher retention rates in their study. In contrast, participants in our first iteration using HL2 encountered significant difficulties with the scrolling interaction, which according to them resulted in lower retention rates. This challenge could be attributed to participants' lack of HL2 experience and limitations in HL2's gesture detection capabilities.

Furthermore, participants experienced less physical fatigue in the fourth iteration compared to the first iteration. The introduction of a dynamic slideshow format in the third and fourth iterations reduced participant errors. Participants preferred this format as it did not require continuous physical engagement, as dynamic scrolling does. However, near-interaction posed challenges for participants, as the narrow FOV limited their ability to view all screens and the physical nature of the interaction caused difficulties. Consequently, we shifted focus to far-interaction in the fourth iteration, allowing for flexible scaling and eliminating the need for physical movement. Participants reported a comfortable and strain-free experience. Far-interaction facilitated the incorporation of varied-sized, detailed, and interactive maps, enhancing their impact on visual storytelling.

The dynamic slideshow genre's interactive nature and segmented storytelling provided versatility in presenting articles, whereas scroll-based interfaces emphasize focus text screens and constant interaction. The slideshow-based interaction enables the map to be the primary storytelling element, with text screens complementing the content. The MR news prototype prioritizes the text screen as the main navigation, giving it the central role. However, in order to emphasize the map as the primary storytelling element, additional testing is necessary to determine the best way to implement a similar interaction.

Our study contradicted the findings of Song et al. (2022) potentially due to variations in study design and the use of HL2 technology. Participants encountered difficulties with scrolling, leading to lower retention rates. The dynamic slideshow format reduced errors and physical fatigue, while far-interaction enhanced user comfort and facilitated the inclusion of interactive maps. The slideshow format enables the map to take center stage in storytelling, with text screens as complementary components and facilitate a variety of map designs. Additionally, it facilitates for a combination of map-based visual storytelling genres.

### Interactive Gestures

In the first iteration, participants expressed a positive reception towards the interactive map, particularly appreciating features such as zooming, panning, and additional information about various locations. Feedback from subsequent iterations indicated a consistent desire for such functionalities on the map. However, participants encountered challenges with navigation during the initial iteration. The allocation of zooming interaction to small buttons on the map's side hindered their preferred one- or two-handed pinching motion. Notably, participants utilized zooming more frequently than panning, highlighting the importance of adapting zooming interactions appropriately for maps in MR. This finding aligns with previous research by Zhou and Bai (2023).

Throughout the iterations, participants expressed interest in alternative interaction methods such as gaze- and voice-based interactions, but they did not wish to replace hand interactions, which they found familiar and natural. This observation aligns with the findings of Zhou and Bai (2023). According to Rudi et al. (2016), head-based interaction can become more subtle and effective as users become accustomed to it, making it a viable option to consider. Subtle interactions could be desirable for public use in the future. Some participants expressed a desire for non-aiming navigation, which could potentially be achieved by combining head- or eye gaze interaction as a pointing mechanism, using the thumb and index finger as a click. However, further testing is necessary to validate this approach. Participants also reported physical strain and discomfort from excessive head movement, indicating the need for optional interaction methods rather than relying solely on head gestures. Additionally, offering multiple interaction methods is crucial to accommodate diverse user preferences and use cases.

Throughout the user tests, difficulties with hand gesture navigation using HL2 were observed. While these challenges may have influenced design choices, they potentially led to improvements in the overall design. As mentioned in the second iteration, the system should not require overly complicated interaction.

The findings suggest that participants appreciated the interactive map in MR for its zooming and panning capabilities. Various alternative interaction methods were desired, including gaze- and voice-based interactions. However, hand interactions remained favored. Care should be taken to address physical strain and discomfort associated with excessive head movement. Multiple interaction methods should be provided to cater to user preferences and use cases.

## Challenges

Throughout the process, we faced several challenges that can be categorized into three main areas: Recruitment of participants, user testing environment, and technical challenges.

### Recruitment

Finding participants is a well-known challenge. Initially, we encountered difficulties in contacting participants with dyslexia and individuals with prior experience using HL2 or comparable extended reality (XR) technologies. Initially, our emphasis was on engaging participants with dyslexia; however, as the study progressed, we modified our approach to minimize reliance on this specific group. Consequently, the recruitment of participants with dyslexia was primarily facilitated through personal networks, due to the limited availability of suitable candidates within the broader population.

The difficulty in finding participants with dyslexia and prior experience with HL2 or similar XR technologies have affected the diversity and representativeness of the user group. This may have influenced the findings and limited the insights gained from specific user demographics.

Since HL2 is not widely utilized in the private market today, we struggled to find participants from our target group with experience using this technology. Nevertheless, many of the participants had some familiarity with other XR technologies, albeit their exposure was limited. None of the participants had prior experience with hand gesture navigation prior to joining the project.

Consequently, our system was tested solely with novice users. While novice users provided valuable insights, their lack of experience may have limited their ability to provide deep insights, potentially resulting in a somewhat one-sided outcome. However, it is worth noting that three participants who took part in the final evaluation had also participated in previous iterations, and they showcased exceptional progress.

Since the system was only tested with novice users, the results may reflect their perspectives and experiences. While novice users provide valuable information, their lack of expertise and familiarity with XR technologies, hand gesture navigation, and HL2 may have resulted in a more limited understanding of the system's capabilities, opportunities, and general user experience.

### User Testing Environment

Due to the limited prevalence of HL2 usage for news consumption or general purposes in everyday life, testing the prototype in users' natural environment posed challenges. Instead, the focus shifted towards establishing a spatially accommodating environment that ensured user comfort during testing.

To facilitate a comfortable testing environment, user evaluations were conducted within closed rooms, with a single participant engaged at a time. This arrangement aimed to mitigate potential observer effects, which could influence participant behavior, particularly considering the novelty of the medium and the expressive nature of navigation.

Nevertheless, conducting individual tests hindered participant communication and collaboration within workshops. Feedback from participants indicated a desire for a more authentic and enhanced experience, preferably in a comfortable environment similar to their own homes.

Considering potential modifications, it is worth evaluating the prospect of granting participants access to an HL2 device, even in the absence of prior exposure or experience. However, such an approach would introduce a distinct set of logistical challenges, encompassing issues of training, guidance, data gathering, and temporal considerations.

Testing of the prototype in a controlled environment, rather than users' natural settings, may have compromised the validity of the findings. Users may behave differently or have different experiences when interacting with the system outside of the testing environment. Thus, the results may not fully represent real-world usage scenarios.

The effort to minimize observer effects by conducting individual tests in closed rooms may unintentionally introduce biases. Participants might alter their behavior or interaction patterns due to the absence of others or the perceived absence of observation. This can influence their engagement with the system and may not accurately reflect how they would use it in a social context.

Participants expressed a desire for a more authentic and comfortable testing environment, such as their own homes. The lack of familiarity and comfort during testing may impact participants' overall experience and potentially affect their performance or feedback. This could have influenced their perception of the system and potentially introduced biases in the results.

Individual testing prevented participants from communicating and collaborating with each other during workshops. The absence of collaborative interaction may limit the exploration of different perspectives, collective problem-solving, and the generation of shared insights. As a result, the depth and breadth of feedback and observations may be reduced.

The challenges associated with HL2 usage and the limitations in participant representation may affect the application of the results. The sample of participants might not fully represent the target user population, particularly those who are experienced with HL2 or similar XR technologies. This could limit the applicability of the findings to a broader user base.

### Technical Challenges

The technical challenges encountered during the process can be attributed primarily to the immaturity of the technology. It was crucial to address these challenges effectively.

One major issue faced was the poor battery life of the HL2 device. During the evaluations, we had to ensure that the device was charged properly. In the first iteration, the device died during a user test. Fortunately, this occurred toward the end of the evaluation, allowing us to complete it. Another challenge was the diminishing responsiveness of the system as testing progressed, which was due to the limited computing power of the HL2.

In one instance, the HL2 crashed, which had a somewhat negative impact on the test. However, we were able to complete most of the test before the crash occurred. To assist users in navigating the HL2, we employed a live stream on a laptop, which proved to be helpful both in guiding participants and facilitating discussions. Before that in the first iteration, we had to temporarily remove the HL2 from the participants to gain a better perspective and guide them back on the right track. However, the live stream had a delay of approximately ten seconds, which often proved to be inconvenient.

The FOV and hand gesture registration of the HL2 were also limiting factors that affected the design of our user-friendly system.

The technical challenges have potentially introduced biases and limitations in the evaluation process. These issues may have disrupted the user experience, affected task performance, and hindered participants' ability to fully explore and interact with the system.

The occurrence of technical difficulties, such as the HL2 device dying during a user test or crashes, could introduce inconsistencies and interruptions in the evaluation process. These incidents may impact the reliability and validity of the collected data and potentially distort the results.

The challenges related to HL2's technical limitations, including the FOV and hand gesture registration, may have influenced the design choices made during the project. The system's user-friendliness and overall usability might have been compromised due to these constraints.

It is important to consider these challenges and their potential implications when interpreting the results of the project. While the findings can still provide valuable insights, they should be understood within the context of the encountered difficulties and limitations.

## Future Work

Improvements to the prototype involve redesigning the text metadata- and map metadata screens, creating a more interactive map, and the utilization of the depth and 3D space offered by the technology. Additionally, it is worth considering the implementation of additional forms of interaction, such as voice and eye/head gaze interaction, to further enrich the user experience by leveraging technologies available in HL2 and numerous XR HMDs.

The primary focus for future development should be the improvement of the map through the integration of interaction possibilities for zoom and pan. It should support various hand interactions, including one and two-handed interactions utilizing the thumb and index finger or the entire hand, to accommodate the most common hand interactions. Additionally, exploring and incorporating head- or eye-gaze and voice navigation should be considered to facilitate diverse user preferences and discover new useful ways to complement far- and near-hand interaction. Efficient methods of presenting metadata should also be explored through further research. Additionally, it is recommended to identify and evaluate different visual storytelling genres for map-based visual storytelling in MR.

The current prototype does not exploit the 3D space provided by MR technology. The scene primarily consists of relatively flat screens. The decision to design the prototype in this manner was based on the realization that the necessary data could be obtained effectively in this chosen format, resulting in significant time savings. However, in the future development of similar prototypes or systems, incorporating interactive 3D elements should be considered to enhance user engagement. Feedback from workshops during the second iteration indicated that users' expectations for these systems encompass a range of interactive elements for visualization and storytelling.

In a study by Yang et al. (2020), a tilt interaction was implemented, allowing users to choose how the map was displayed, thus optimizing the benefits of both 2D and 3D maps. Integrating a similar function in MR news could be intriguing. However, it should be noted that the tilt interaction in their study was assigned to a VR controller and cannot be directly transferred. Further exploration is necessary to determine the most suitable implementation, which could potentially involve the addition of a slider or the ability to grab the edge of the map.

A feature that dynamically controls the level of immersion in the experience would be valuable to test, similar to the functionality of Tilt Map. As the medium of MR provides situational awareness, it can be utilized in diverse settings, such as walking outside, sitting on a bus, or in small spaces. To accommodate this variety of use cases, designs should adapt to different environments. In situations where users are static in large spaces, a more immersive experience may be desirable. However, in tight spaces or public areas, individuals may prefer to maintain a higher degree of situational awareness, requiring more subtle gesturing. Therefore, the design should be flexible enough to accommodate these preferences. It would be beneficial to establish breakpoints that determine the level of immersion in the design. Users should have the ability to adjust this parameter, similar to resizing a browser on a desktop, where the layout adapts to the given size. This may include determining the amount of space occupied by elements and whether everything is displayed simultaneously. In maximum immersion mode, images or animations could be presented in a 360-degree format, while scaling down the immersion would result in smaller visuals, providing a greater level of situational awareness.

# 6. Conclusion

Mixed Reality (MR) technology has opened completely new ways of interacting with technology. In the context of news articles storytelling and maps, there exists a significant opportunity to enhance communication through the immersive and engaging experiences they offer to users. By effectively leveraging these mediums, the news media can better captivate audiences and effectively convey their message. Through a Research through Design (RtD) process, this study aimed to answer the Research Question (RQ): How can we design map-based interactions in regard to visual storytelling genres and interactive gestures for news articles in Mixed Reality?

A prototype named MR news was created utilizing Unity and the Mixed Reality Tool Kit (MRTK) within the framework of the RtD methodology. The RtD process contained four iterative cycles, each encompassing scoping, design process, user evaluation, and reflection stages.

This iterative approach ensured that the prototype progressed with each iteration, resulting in a more refined and user-friendly MR experience for consuming news content. The prototype now encompasses various components, such as a picture screen for visual representations, a text-metadata screen that offers supplementary information to the text screen, an interactive map screen for providing geographical context, and a map-metadata screen with detailed data about the specific areas affected by the discussed phenomena. These additions contribute to a more comprehensive and immersive MR news consumption experience.

The study discovered several important findings. It revealed increased participant engagement, suggesting a higher level of story engagement. Such findings indicate the potential for leveraging map-based interaction in MR as a powerful tool in augmenting visual storytelling, thereby amplifying user interest and involvement in news consumption. Furthermore, it is evident that the principles of storytelling and interaction should not be directly transferred from traditional PC interfaces to MR HMDs due to fundamental differences in interface and interaction.

Regarding visual storytelling genres, the study contradicted previous research on longform infographics, highlighting the importance of considering the platform and interface when evaluating user retention rates. The dynamic slideshow format proved to be more effective in reducing errors and physical fatigue compared to scrolling interactions in MR news. Far-interaction, with its flexible scaling and reduced physical movement, provided a comfortable and strain-free experience, enhancing the impact of interactive maps in visual storytelling. The results also indicate that it could be beneficial to combine some of the characteristics from other storytelling genres.

In terms of interactive gestures, participants expressed a positive reception towards zooming and panning capabilities on the interactive map. Alternative interaction methods, such as gaze- and voice-based interactions, were desired but not to the extent of replacing hand interactions, which participants found familiar and natural. It is crucial to address physical strain and discomfort.

The study encountered challenges related to participant recruitment, user testing environment, and technical limitations of the HL2 device. Difficulties in recruiting participants with prior experience with HL2 or similar XR technologies affected the diversity and representativeness of the user group. Testing the prototype in a controlled environment rather than users' natural settings and technical issues with the HL2 device posed additional challenges.

Future work should focus on improving the interactive map by integrating zoom and pan functionalities and exploring additional interaction methods like gaze- and voice-based interactions. The incorporation of interactive 3D elements and tilt interactions can further enhance user engagement. Designing for different levels of immersion and situational awareness and allowing users to adjust the immersive experience based on their preferences and context, should be considered. Additionally, exploring different visual storytelling genres for map-based visual storytelling in MR is recommended.

# 7. References


Azuma, R. T. (1997). A survey of augmented reality. *Presence: teleoperators & virtual environments*, *6*(4), 355-385.

Clarke, V., Braun, V., & Hayfield, N. (2015). Thematic analysis. *Qualitative psychology: A practical guide to research methods*, *222*, 248.

Dæhlen, M. (2021). Ti prosent av oss orker ikke følge med på nyheter. *forskning.no*. https://forskning.no/internett-media-mobiltelefon/ti-prosent-av-oss-orker-ikke-folge-med-pa-nyheter/1820537

Giannopoulos, I., Komninos, A., & Garofalakis, J. (2017). *Interacting with large maps using HMDs in VR settings* Proceedings of the 19th International Conference on Human-Computer Interaction with Mobile Devices and Services, Vienna, Austria. https://doi.org/10.1145/3098279.3122148

Goode, L. (2019). *Microsoft's HoloLens 2 Puts a Full-Fledged Computer on Your Face*. Wired. https://www.wired.com/story/microsoft-hololens-2-headset/

Herrera Damas, S., & Benítez de Gracia, M. J. (2022). Immersive Journalism: Advantages, Disadvantages and Challenges from the Perspective of Experts. *Journalism and Media*, *3*(2), 330-347. https://www.mdpi.com/2673-5172/3/2/24

Koskinen, I., Zimmerman, J., Binder, T., Redstrom, J., & Wensveen, S. (2011). *Design Research Through Practice : From the Lab, Field, and Showroom*. Elsevier Science & Technology. http://ebookcentral.proquest.com/lib/bergen-ebooks/detail.action?docID=767255

Kvalheim, F. J. (2023). Dette skal være Apples lanseringsplaner. *Tek.no*. https://www.tek.no/nyheter/nyhet/i/WRdoJk/dette-skal-vaere-apples-lanseringsplaner?utm_source=vgfront&utm_content=hovedlopet_row11_pos1&utm_medium=dre-646e4153868247a3093ad155

Lim, Y.-K., Stolterman, E., & Tenenberg, J. (2008). The anatomy of prototypes: Prototypes as filters, prototypes as manifestations of design ideas. *ACM Trans. Comput.-Hum. Interact.*, *15*(2), Article 7. https://doi.org/10.1145/1375761.1375762

Microsoft. (2023). *Learn Microsoft HoloLens*. Microsoft. https://learn.microsoft.com/en-us/hololens/

Milgram, P., Takemura, H., Utsumi, A., & Kishino, F. (1995). Augmented reality: A class of displays on the reality-virtuality continuum. Telemanipulator and telepresence technologies,

Mordor, I. (2023). *EXTENDED REALITY (XR) MARKET SIZE & SHARE ANALYSIS - GROWTH TRENDS & FORECASTS (2023 - 2028)*. Mordor Intelligence. https://www.mordorintelligence.com/industry-reports/extended-reality-xr-market

Mullaney, T. (2016). Apple product innovations that changed the world. *CNBC*. https://www.cnbc.com/2016/04/29/apple-product-innovations-that-changed-the-world.html

Precedence, R. (2022). *Extended Reality Market - Global Industry Analysis, Size, Share, Growth, Trends, Regional Outlook, and Forecast 2022-2030*. Precedence Research. https://www.precedenceresearch.com/extended-reality-market

Pritchard, T. (2023). *Apple VR/AR headset - everything we know so far*. https://www.tomsguide.com/news/apple-vr-and-mixed-reality-headset-release-date-price-specs-and-leaks

Roth, R. E. (2013). Interactive maps: What we know and what we need to know. *Journal of Spatial Information Science*(6), 59-115.
Roth, R. E. (2021). Cartographic Design as Visual Storytelling: Synthesis and Review of Map-Based Narratives, Genres, and Tropes. *The Cartographic Journal*, *58*(1), 83-114. https://doi.org/10.1080/00087041.2019.1633103
Rudi, D., Giannopoulos, I., Kiefer, P., Peier, C., & Raubal, M. (2016). *Interacting with Maps on Optical Head-Mounted Displays* Proceedings of the 2016 Symposium on Spatial User Interaction, Tokyo, Japan. https://doi.org/10.1145/2983310.2985747
Schnotz, W. (2002). Commentary: Towards an Integrated View of Learning from Text and Visual Displays. *Educational Psychology Review*, *14*(1), 101-120. https://doi.org/10.1023/A:1013136727916
Song, Z., Roth, R. E., Houtman, L., Prestby, T., Iverson, A., & Gao, S. (2022). Visual Storytelling with Maps: An Empirical Study on Story Map Themes and Narrative Elements, Visual Storytelling Genres and Tropes, and Individual Audience Differences. *Cartographic Perspectives*(100), 10–44. https://doi.org/10.14714/CP100.1759
Taqtile. (2016). *HoloMaps by Taqtile*. Microsoft. https://www.microsoft.com/en-us/p/holomaps-by-taqtile/9nblggh3zrtd?activetab=pivot:overviewtab
Yang, Y., Dwyer, T., Marriott, K., Jenny, B., & Goodwin, S. (2020). Tilt Map: Interactive Transitions Between Choropleth Map, Prism Map and Bar Chart in Immersive Environments. *IEEE Transactions on Visualization and Computer Graphics*. https://doi.org/10.1109/TVCG.2020.3004137
YouGov. (2020). FIRST IN LINE: EARLY TECHNOLOGY ADOPTERS AROUND THE GLOBE. https://commercial.yougov.com/rs/464-VHH-988/images/Global-Technology-2020.pdf
Zhou, X., & Bai, R. (2023). User-defined mid-air gestures for multiscale GIS interface interaction. *Cartography and Geographic Information Science*, 1-14. https://doi.org/10.1080/15230406.2023.2183900
Zimmerman, J., & Forlizzi, J. (2014). Research Through Design in HCI. In J. S. Olson & W. A. Kellogg (Eds.), *Ways of Knowing in HCI* (pp. 167-189). Springer New York. https://doi.org/10.1007/978-1-4939-0378-8_8
Zimmerman, J. a. F., Jodi and Evenson, Shelley. (2007). Research through Design as a Method for Interaction Design Research in HCI. 493–502. https://doi.org/10.1145/1240624.1240704
Zimmerman, J. a. S., Erik and Forlizzi, Jodi. (2010). An Analysis and Critique of Research through Design: towards a formalization of a research approach. 310–319. https://doi.org/10.1145/1858171.1858228