

# EMBODIED DATA

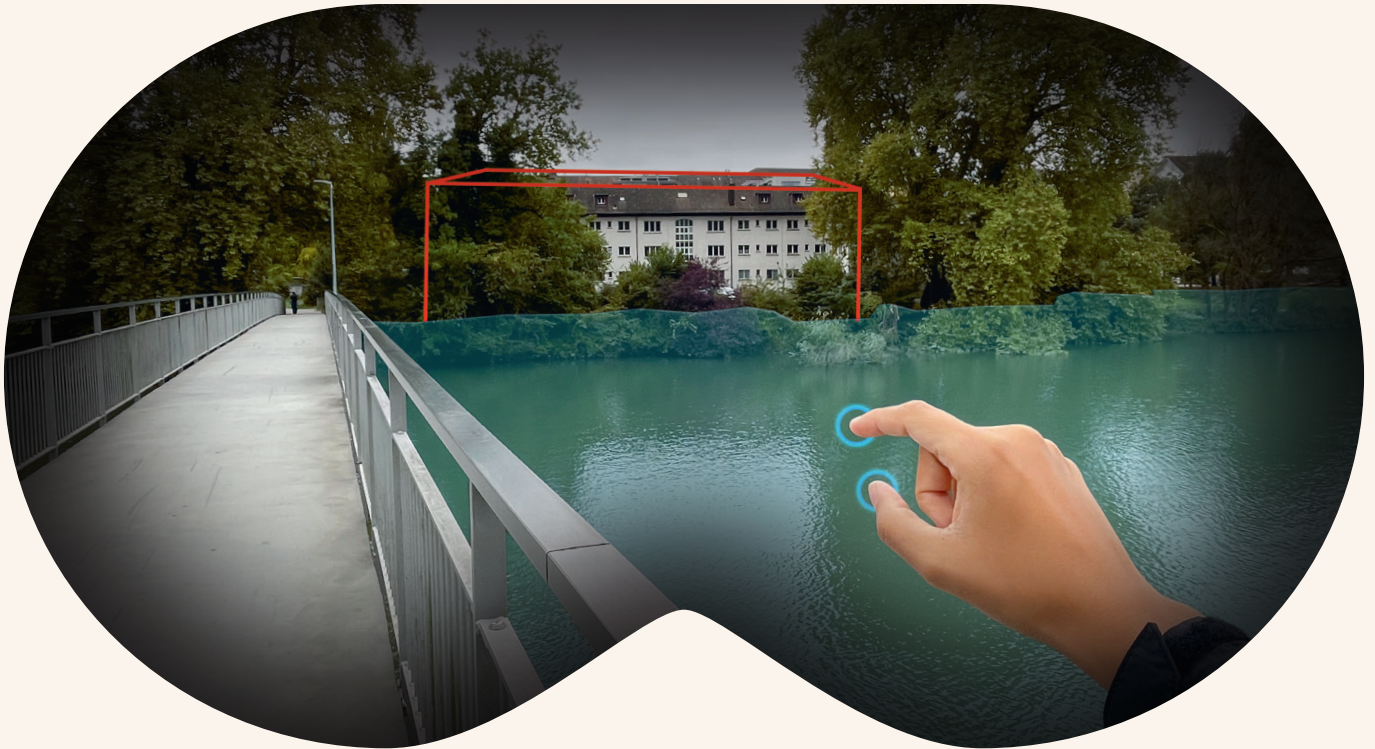
A MIXED REALITY APPROACH  
TO ENVIRONMENTAL INFORMATION

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MA Design Thesis  
Lucerne School of Art and Design  
Master of Arts in Design: Master Digital Ideation

Thesis Supervisors: Karin Fink & Robert Bossart

# **PART 1: RESEARCH THESIS**



# PLACING ENVIRONMENTAL DATA INTO CONTEXT

EXPLORING THE POTENTIAL OF MIXED REALITY FOR NATURAL HAZARD COMMUNICATION

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# ABSTRACT

Switzerland's natural hazards are becoming increasingly complex and unpredictable due to climate change and urban development. While the country maintains sophisticated hazard monitoring and risk management, conventional visualization methods often struggle to connect with non-expert audiences.

This thesis explores how Mixed Reality (MR) technologies can address this challenge by introducing “**spatially intuitive communication**” as a new design approach that builds on audience-centered design from risk communication theory, visualization research showing contextual approaches improve comprehension, and insights about how physical engagement lowers barriers to complex information systems.

The research results in practical design guidelines for Mixed Reality applications in environmental risk communication, positioning MR as a complement to existing tools rather than replacement. These guidelines prove particularly relevant to Switzerland's shared responsibility model for risk management, where effective preparedness depends on common vocabulary and shared understanding among stakeholders.

# AFFIDAVIT

I hereby solemnly declare that I have independently prepared this MA thesis.

Ideas directly or indirectly taken from outside sources are indicated as such.

The work has not previously been presented to another examination authority nor otherwise published in the same or similar form.

While writing the thesis, I used AI-powered tools to assist with writing and research processes. AI tools were used to assist with writing style, organization, and revision, but all core ideas, analysis, and arguments remain my own work.

ChatGPT (<https://chatgpt.com> , GPT-5) was used in the early research process to help identify related literature and research directions. It also helped structure and reorganize notes and create early outlines.

Claude AI (claude.ai, Sonnet 4) was used to help declutter text, identify gaps in arguments, and provide feedback on content structure and writing style. It also assisted with abstract drafting and revision.

DeepL (DeepL.com) was used for translation purposes.

Lucerne, 26.09.2025

A handwritten signature in black ink, appearing to read 'S. J. ...' with a large, stylized initial 'S'.

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# 1. INTRODUCTION

Switzerland, with its diverse topography of mountains and bodies of water, is prone to natural hazards (FOEN, 2025, Natural Hazards: In Brief). The recent rockslide in Blatten VS (28.05.2025) (Fig. 2) that buried a village under its mass demonstrates that natural hazards are neither distant nor abstract.

They are real.

They are local.

And they are increasing in frequency, intensity, and unpredictability.

The latter is a trend driven by climate change and urban development. (FOEN, 2025, Natural Hazards: In Brief).

Switzerland has widely respected risk management and is therefore well prepared in many technical and organizational aspects (Höppner et al., 2010), as evidenced by the successful evacuation of Blatten before the rockslide occurred.

In recent years we have seen a paradigm shift toward more participatory approaches to natural hazard management, recognizing that effective preparedness requires dialogue among all stakeholders. This participatory approach demands, what pilot projects like "Reise zum akzeptierten Risiko" (Journey to Accepted Risk) have identified as essential, a shared vocabulary that allows non-experts to meaningfully engage in discussion (FOEN, 2021).

A key challenge is how natural hazards are typically represented. Complex three-dimensional processes, for example rockfall trajectories, are often flattened into abstract two-dimensional maps or datasets. While Switzerland maintains abundant and sophisticated hazard data, these formats strip away the spatial context that non-experts need to understand how risks might affect their daily lives and familiar environments.

This thesis explores how Mixed Reality (MR) can address this challenge by re-contextualizing environmental data into its original spatial context. MR's ability to overlay digital information directly onto real-world environments offers new possibilities for risk communication.

To guide this exploration, the research introduces spatially intuitive communication as a design approach, which uses people's spatial thinking ability as a foundation for communicating complex information.

This leads to the core research questions:

How can Mixed Reality be used to support more accessible and spatially intuitive communication of natural hazards?

What design guidelines can inform future applications in that domain?

This research builds on the premise that understanding risks depends not only on access to data, but on how that data is communicated and experienced. Drawing from different research areas, it makes both conceptual and practical contributions. First, it develops spatially intuitive communication as a design approach that extends existing theories of risk communication and visualization. Second, it proposes concrete design guidelines for Mixed Reality applications that can make natural hazards more tangible to diverse audiences.



Fig. 2: Blatten (VS) days after rockfall in May 2025 (SRF, 2025)

## 2. RESEARCH APPROACH AND METHODOLOGY

This thesis uses a qualitative, design-oriented research approach. It emphasizes interpretive analysis and inductive reasoning, recognizing the researcher's role in shaping how literature and theory are synthesized and assessed for their relevance to future design projects.

Secondary research builds the foundation, drawing on literature about natural hazards, risk communication, data visualization, and immersive technologies. Rather than presenting the theoretical foundation in isolation, the analysis is woven throughout the thesis, contextualized with case studies and prototype examples. These examples are not treated as empirical evaluations but as illustrative touchpoints.

Through this integrated approach, the thesis develops the concept of spatially intuitive communication (chapter 7). This term is proposed as a new design approach for understanding how immersive technologies can make environmental risks more tangible and personally meaningful.

The synthesis leads to the formulation of design guidelines that serve as principles to support future projects using the spatially intuitive communication approach.

### 2.1. SECONDARY RESEARCH

The method involves systematic review of academic literature, official Swiss and international reports, policy documents, and documented case studies. The cross-disciplinary synthesis enables the identification of recurring challenges in environmental risk communication while revealing how emerging technologies might address these limitations. The secondary research provides the theoretical foundation necessary for developing spatially intuitive communication as a design approach.

### 2.2. RESEARCH THROUGH DESIGN

Early prototyping helped identify the research opportunity and informed the theoretical direction. The hands-on experiences revealed the potential of immersive technologies to recontextualize environmental data.

### 2.3. CASE STUDY ANALYSIS

Selected case studies provide illustrative examples of current visualization approaches in environmental risk communication. Some examples offer Swiss specific context, while other projects demonstrate different approaches to making technical information accessible to public audiences. These cases serve as reference points.

### 2.4. ANALYTICAL PROCESS

The development of spatially intuitive communication emerged from recognizing how three-dimensional environmental processes lose spatial context when flattened into conventional two-dimensional formats. This led to research into how this challenge manifests across risk communication, data visualization, and immersive technology domains. The design approach was subsequently

developed to address this challenge of preserving spatial context in environmental communication.

The design guidelines developed in this thesis synthesize the insights into practical recommendations, providing actionable guidance for practitioners.

## 3. NATURAL HAZARDS IN SWITZERLAND

“Living in Switzerland means having to face natural hazards.”  
(FOEN, 2025, Facing natural hazards)

Natural hazards are defined as natural events that pose threats to society, infrastructure, and the environment. When such a hazard leads to actual damage, it is classified as a natural disaster. (Hohmann et al., 2003). In Switzerland, these events are deeply embedded in both the physical landscape and the social systems that manage them, creating challenges that are not only environmental but fundamentally communicative and social. (FOEN, 2025, Natural hazards: In brief)

In Switzerland, the management of natural hazards has a long tradition, but climate change is intensifying both the frequency and complexity of extreme events. Alongside this, rapid urban development creates additional challenges, as expanding settlements and large-scale infrastructure projects increase exposure and even generate new risk zones. This is an opportunity for new strategies and communication tools. (FOEN, 2024)

This chapter outlines the key characteristics of natural hazards in Switzerland, the paradigm shift toward integrated risk management, and the communication challenges that emerge from the country's approach to shared responsibility. It establishes the foundation for understanding what spatially intuitive communication can contribute to the diverse stakeholders involved in Switzerland's hazard management.

### 3.1. SWITZERLAND'S CHANGING RISK LANDSCAPES

“Our approach to natural hazards has reached a high level and is also recognized internationally. However, we are now facing new challenges: climate change is increasing the risk posed by natural events. Due to higher temperatures and changes in precipitation patterns, a significant increase in debris flows, landslides, rockfalls, and floods is to be expected. The dangers are not only increasing in mountainous areas; the whole of Switzerland must prepare for new scenarios, such as more frequent and intense rainfall, which could also flood your basement.” (Steffen, 2020)

This statement by Paul Steffen (Vice Director FOEN, 2020) captures a growing reality: Switzerland is entering a new era of environmental uncertainty. Natural hazards which were previously perceived as seasonal and geographically confined, are evolving in frequency, complexity, and impact.

In Switzerland, natural hazards are typically categorised into three categories (HEV, 2025; VKF, 2025):

- Meteorological natural hazards are hazards that arise from short-term weather phenomena such as snow, storms, hail, heatwaves, and heavy rainfall.
- Gravitational natural hazards are hazards that arise from the flow, sliding, or falling of water (debris flows), earth masses (landslides), rocks (rockfall), or snow (avalanches).
- Geological hazards like earthquakes, radon exposure, and tectonic activity.

Climate change introduces additional dimensions to the natural hazard landscape: creeping phenomena like drought, new risks such as wildfires, and complex cascades where multiple hazards interact. The cascade effect makes them harder to forecast and more difficult to manage. (FOEN, 2025, Natural hazards: In brief; umwelt magazine, 2020).

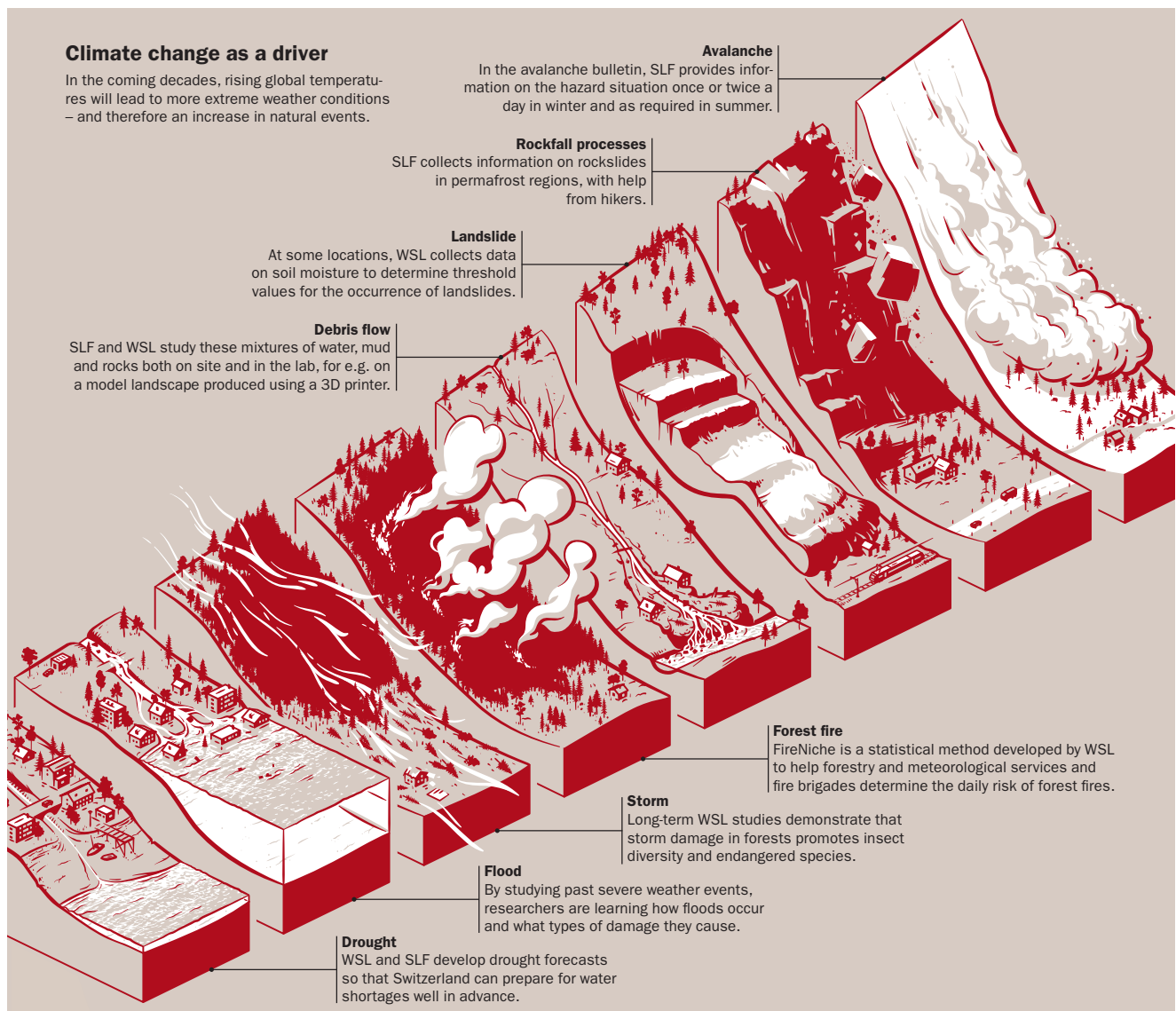


Fig. 3: Overview of natural hazards in Switzerland and what data the WSL and SLF collect (WSL Magazine Diagonal, 2025)

### 3.2. SPATIAL AND LOCAL SPECIFICITY

Natural hazards are deeply tied to geography. The country's topography shapes where and how risks manifest. Hazards such as rockfall or avalanches are highly localized, sometimes threatening individual roads or villages, while tectonic hazards like earthquakes, although very rare in Switzerland, could potentially affect wider regions.

Experts often emphasize that natural hazards are hyper-local in Switzerland, meaning that hazards are not only distributed uneven across the country, but that even within a small valley, risks can differ dramatically depending on land use. (BAFU, 2020)

This spatial specificity creates distinct challenges for risk communication. For example, traditional hazard maps, while technically accurate, are difficult for non-experts to interpret in relation to their specific situations (Grainger et al., 2016; Hullman, 2020). A single map might show a red hazard zone that encompasses both a safely elevated road and a vulnerable building in a low-lying area, but translating these abstract zone designations into understanding of personal risk requires specialized data literacy skills. The same hazard can translate to very different risk levels depending on exact location, building materials, and local topographic features.

This hyper-local variability demands not only regionally differentiated management strategies but also location-sensitive communication approaches. Effective communication must be able to address questions like: “What does this flood scenario mean for my specific street?” or “How would rockfall patterns affect my daily route to work?”

These communication challenges point toward the need for new approaches that can keep spatial context during risk communication. Instead of asking residents to mentally translate zone maps onto their surroundings, location-based overlays could present hazard scenarios in places where decisions about preparedness must be made.

This potential aligns particularly well with Switzerland's municipal-level governance of natural hazards, where local knowledge and site-specific decisions play crucial roles in effective risk management. Communication tools that work at the scale of neighborhoods and individual properties could support the locally grounded preparedness that Switzerland's hazard management approach requires.

### 3.3. PARADIGM SHIFT: FROM PREVENTION TO INTEGRATED RISK MANAGEMENT

Traditionally, Switzerland's approach to natural hazards emphasized hazard prevention through structural measures. However, a paradigm shift has taken place in recent years, moving toward integrated risk management approaches. As the Homeowners Association Switzerland (HEV, 2025) outlines, this includes “structural, biological, planning, and organizational approaches,” but also emphasizes prevention before events, insurance, and citizen responsibility after events.

**CASE STUDY****REISE ZUM AKZEPTIERTEN RISIKO  
(JOURNEY TO ACCEPTED RISK)**

The “Journey to Accepted Risk” (RaR) represents Switzerland's shift toward participatory risk management. Developed as part of the national climate adaptation program, RaR brings together authorities, planners, and local stakeholders through an eight-step process to collectively assess natural hazard risks and negotiate which risks are acceptable and which require targeted mitigation.

The process emphasizes development of shared vocabulary among diverse participants. As the project documentation (SLF, 2023) states, solutions can only be found when “the various affected and involved parties develop a common picture of the risks from the outset.”

Key questions include: What are the essential risks? Which risks do we accept? What is important to us? Where do we intervene to reduce unaccepted risks?

RaR's participatory approach addresses a fundamental communication challenge: meaningful participation in risk decisions requires common ground for understanding technical information and local concerns. The process creates structured opportunities for dialogue rather than top-down expert assessments, supporting Switzerland's shared responsibility model for natural hazards.

An example of this paradigm shift is the pilot project “Reise zum akzeptierten Risiko” (RaR, translation: Journey to Accepted Risk), developed as part of Switzerland’s national adaptation program to climate change. RaR introduces a participatory, step-by-step process that brings together authorities, planners, and local stakeholders to develop a shared understanding of natural hazard risks and to decide collectively which risks are acceptable and which require targeted mitigation. By emphasizing dialogue and shared responsibility, the project shifts risk communication away from fixed expert assessments toward negotiated understandings, aiming for solutions that are ecologically, economically, and socially balanced. (SLF, 2023)

An important insight from RaR, and one particularly relevant for this thesis, is that participation requires a shared vocabulary. For dialog between different stakeholders to be meaningful and relevant a common ground is vital. Without it discussions risk becoming stalled or dominated by technical language. Thus, RaR shows that communication tools must not only deliver information but create accessible entry points into complex topics, enabling non-experts to join substantive decision-making.

In the context of this thesis, RaR is a valuable case study that illustrates how design interventions, whether participatory workshops or immersive simulations, can support a shared sense-making process around risk, rather than one-way information transfer.

This also indicates the need for new communicative tools: if shared vocabularies are essential for participatory processes, then new design approaches that make hazard information more tangible and accessible can play a role in creating the conditions for meaningful dialogue.

### 3.4. IMPACTS ON PEOPLE AND SOCIETY

Natural hazards occur where natural and human systems intersect (Fig. 5,6). For example, an avalanche in a remote and uninhabited mountain valley is no danger to humans. However, in a popular tourist resort, the potential damage, and therefore the natural hazard, can be extremely high. This shows that hazards only become problems only when they affect with human life. (Dikau & Voss, 2025)

Swiss examples show clear impacts: in Guttannen, repeated rockfalls blocked the Grimselpass road and disrupted mobility. In Bondo, the 2017 debris flow caused cancelled bookings and lasting losses in tourism. Impacts on buildings range from flooded basements to severely damaged structures.

The psychological consequences including stress, fear, and trauma often linger long after physical reconstruction. For affected people, the hazard is not only a geophysical phenomenon but a disruption to safety and identity.

The same hazard will impact people differently based on their individual situation. An elderly person might struggle to evacuate quickly. Someone who doesn't speak the local language might miss warning messages. A family with young children needs more time to prepare and different types of information. The degree to which people are impacted is therefore influenced by their individual vulnerability and resilience. Vulnerability to natural hazards in Switzerland is not predetermined by generational or socioeconomic categories. (Saunders et al., 2025; Steinemann et al., 2025)

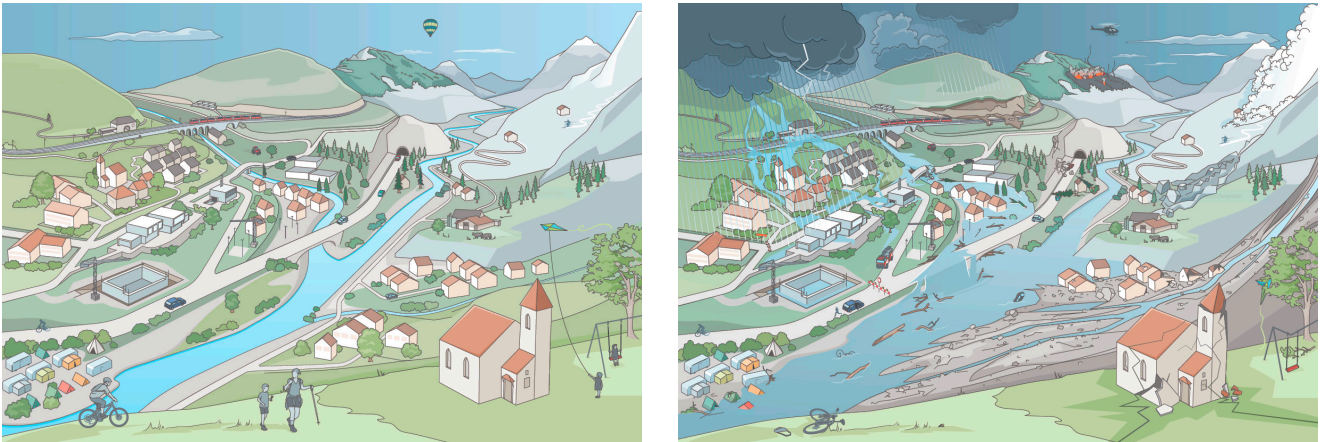


Fig. 5,6: Illustration of natural disaster in Switzerland (FOEN, 2025, Facing natural hazards)

### 3.5. STAKEHOLDERS AND SHARED RESPONSIBILITY

Civic engagement plays a pivotal role in Switzerland's approach to natural hazards management, as the Federal Office for the Environment sees them as shared responsibility: “Every person and institution bears risks from natural hazards – both for themselves and for society. In addition, people influence the level of risk through their actions. As such, we are all stakeholders when it comes to dealing with natural hazards – albeit in different roles.” (umwelt magazine, 2020)

When analyzing the key stakeholders involved in natural hazard management, three main groups emerge (Fig. 7) (FOEN, 2025, Facing natural hazards):

1. **Public Authorities:** Develop strategies, provide information (e.g., hazard maps, legal frameworks), implement protection measures, and warn the population.
2. **Insurance Companies:** Assess risks, advise homeowners and businesses, and offer financial protection against damages caused by natural hazards (e.g., hail, storms, earthquakes).
3. **Potentially Affected Persons:** Take precautions, protect their own property, and prepare for emergencies.

In risk management a shared understanding among all stakeholders is essential (SLF, 2023). However, each group views hazards differently. Authorities rely on technical assessments and regulations, insurers on actuarial models, and residents just want what is best for them. What represents acceptable risk from a regulatory perspective may feel unacceptable from a personal safety perspective, and technical classifications that work for insurance assessments may not translate effectively to individual preparedness decisions.

These interpretation challenges point toward the need for communication approaches that can create common ground across diverse perspectives. When risk information can be anchored to shared spatial references, the same buildings, roads, and landscapes that all stakeholders recognize, it may serve as a foundation for dialogue that bridges different knowledge systems and concerns, supporting the shared understanding that effective risk governance requires.

As discussed in chapter 3.3, a shared understanding between these groups is essential. Yet complex data alone rarely creates such alignment. As Hullman (2020) and Paul (2016) argue, more data does not necessarily lead to more insight, particularly when it is probabilistic or difficult to interpret. Instead, risk communication tools must translate hazards into actionable information. This supports the need for clear, accessible communication and visualizations that empowers people, not only experts.

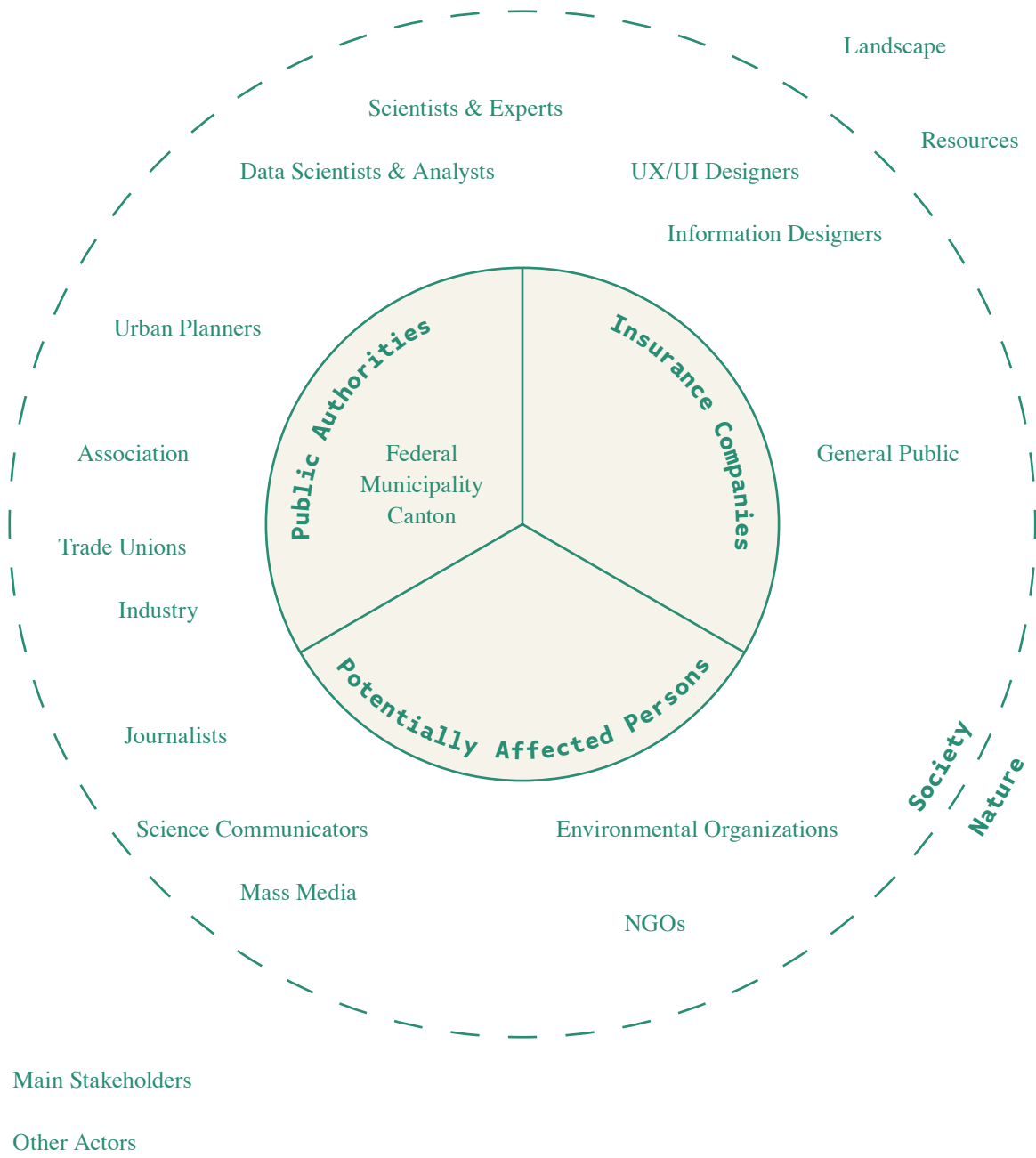


Fig. 7: Stakeholder Map

### 3.6. GEODATA

The way experts in Switzerland monitor and collect data on natural hazards has evolved significantly over the past decades, providing a wealth of information. Sophisticated systems now collect data on rainfall, slope movement, water levels, snow conditions and much more. Authorities maintain databases that feed real-time warning systems and inform long-term planning. Because of Switzerland's Open Data policy much information is made publicly accessible through online platforms and digital maps. (FOEN, 2025, GIN; opendata.swiss, 2025)

Natural hazards are dynamic process that unfold in space and time. Their effects, whether damaging or avoidable, depend on where they occur and who or what lies in their path. This makes geospatial data indispensable for understanding and managing these risks.

**Geodata** (Geographic Data) refers to information that can be assigned to a spatial location. Such a georeference could be coordinates or indirect assignment to an administrative area (country, city, street). (“Geodaten”, 2023)

**Environmental data** is data, that is related to and describes the natural. Georeference is not mandatory, and it is usually subject to a temporal dimension. (“umweltdaten,” 2025)

It provides a quantifiable basis for understanding environmental conditions, trends, and the effectiveness of interventions. Therefore, playing a critical role in informing decision-making across various sectors. (“Environmental Data”, 2025)

Geodata is not inherently environmental data, though there is significant overlap between the two. Environmental science heavily relies on spatial analysis, making geodata tools essential for environmental research. Additionally, many environmental phenomena are inherently spatial: pollution spreads geographically, ecosystems exist in specific locations, climate varies by region and natural hazards are very local.

However, geodata is simply a way of organizing and analyzing information based on location. The subject matter of that information can be environmental, social, economic, political, or any other domain where location matters. So, while environmental data is often geodata, geodata encompasses much more than just environmental information.

But while this data is critical from a scientific and operational perspective, it does not automatically translate into public understanding or personal action. The shift from technical geodata to communicative risk insight remains a challenge.

Data visualization offers a powerful tool to address this issue. As “Visualization can help portray complex issues, which in turn can support civic engagement.” (Dörk et al., 2018)

## 4. ENVIRONMENTAL RISK COMMUNICATION

The following sections draw heavily from the findings of the CapHaz-Net Report on “Risk Communication and Natural Hazards” (Höppner et al., 2010).

### 4.1. DEFINITION & SCOPE

Risk communication can be broadly defined as a social process of information exchange about risk (individual, social, political, environmental) that is purposeful or non-purposeful. (Höppner et al., 2010)

Early approaches were grounded in the Shannon and Weaver (1948) sender-receiver model (Fig. 8), where communication is the intentional transfer of information from experts to the public. With emphasis on the purpose and quality of the information provided (Plough & Krimsky, 1987).

Over time, however, this linear model has shifted toward more dialogical exchange, where knowledge, values, and opinions circulate between stakeholders (Fig. 7). Communication is therefore no longer only about broadcasting hazard information but about fostering trust and preparedness. (Höppner et al., 2010)

Building on this, the thesis takes inspiration from the participatory spirit of newer models while keeping the scope realistic. Rather than full participation, the focus lies on how visualizations and immersive environments can encourage exploration, allowing users to reach their own conclusions, and foster agency.

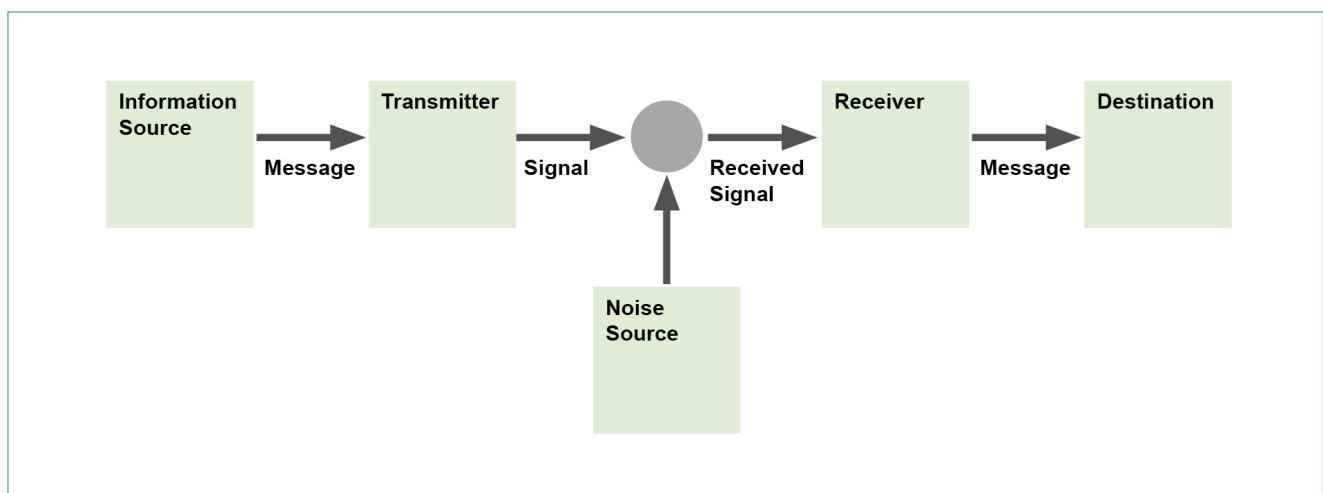


Fig. 8: Sender-Receiver Model (Höppner et al., 2010)

## 4.2. PURPOSE & FUNCTION

The purposes of risk communication vary by phase:

before (communication is mainly preventive),  
during (centers on warnings and instructions),  
and after hazard events (shifts to recovery, reflection, and rebuilding trust).

This thesis is limited to the before phase, as it aims to increase preparedness. This also distinguishes risk communication in this thesis from crisis, or emergency communication, which is reactive and focused on immediate warnings and post-event coordination (Höppner et al., 2010).

Three core principles are especially relevant:

- **Inform, Educate and Motivate Protective Action**
- **Build Trust and Credibility**
- **Enable Shared Responsibility**

For this thesis, the focus lies on visual and immersive approaches that bridge awareness-raising with exploratory interaction. While not fully participatory, such approaches can open space for audiences to move from passive reception toward active decision-making.

## CHALLENGES IN RISK COMMUNICATION

Turning these purposes into practice is not straightforward. Research highlights recurring challenges that shape how communication is received and acted upon (Höppner et al., 2010; Paul, 2016)

Hazards rarely occur in isolation, with floods triggering landslides and storms leading to debris flows. Simplifying these complex dynamics without losing nuance is difficult (Höppner et al., 2010). Then there is the perception gap, where the public often underestimates long-term or invisible risks compared to expert assessments, limiting preparedness and engagement (Paul, 2016).

Communication challenges extend beyond technical complexity to social dynamics. Stakeholders frequently disagree on acceptable risk levels and fairness of measures, creating conflict. Successful protective infrastructure can paradoxically create false security through the “levee effect”, encouraging settlement in hazard-prone areas (Höppner et al., 2010).

Underlying all these challenges are fundamental trust and uncertainty issues. Probabilistic forecasts remain difficult to communicate, with transparency either strengthening or weakening trust depending on context (Lundgren & McMakin (2009); Frewer, 2004). Trust proves central to all risk communication. Once lost, it becomes difficult to rebuild, requiring approaches that maintain “critical trust” where people remain engaged and reflective. (Höppner 2010)

These challenges act as design constraints for communication tools. For example, perception gaps call for visualizations that connect abstract data to familiar environments; uncertainty requires clear visual encoding that preserves complexity, and trust demands visible data sources and transparent methodologies.

### 4.3. PRINCIPLES OF GOOD RISK COMMUNICATION

Building on the purposes and challenges of risk communication, the CapHaz-Net report (Höppner et al., 2010) and related literature emphasize several guiding principles that help ensure communication is both effective and trustworthy.

#### Transparency and Openness

Effective communication requires honesty about what is known and unknown. This includes acknowledging uncertainties, explaining why they exist, and clarifying what can or cannot be done to reduce them (Lundgren & McMakin, 2009).

#### Clarity and Accessibility

Complex information must be presented in ways that are understandable to non-experts. This does not mean oversimplifying hazards but finding formats that allow people to grasp the relevance (Grainger et al., 2016). Accessibility includes attention to different audiences.

#### Dialogue and Participation

Communication is most effective with interaction. This is especially important in contexts where risk management requires shared responsibility. Tools that allow exploration or participatory engagement, even at a basic level, help move communication beyond passive reception. (Höppner et al., 2010)

#### Trust and Relationship-Building

Trust is central to all risk communication. Once broken, trust is difficult to rebuild, which is why openness and continuity in communication are crucial. (Walls et al., 2004)

#### Context-Sensitivity

Messages must be tailored to local risk profiles, cultural expectations, and institutional settings. In Switzerland, where responsibility is shared across multiple levels of governance, context-sensitive communication ensures that advice feels relevant, actionable, and fair.

These principles underline that good communication is not only about technical accuracy but also about designing for accessibility and trust.

#### 4.4. THE ROLE OF MEMORY IN RISK COMMUNICATION

When disasters fade from memory, the sense of urgency often fades with them, which can lead to complacency or underestimation of risk.

This phenomenon is described as disaster amnesia. It is the tendency of societies and individuals to “forget” past events over time, especially when new generations have not directly experienced them. (Birkholz et al., 2014)

Closely related is the normalcy bias, a cognitive bias that leads people to underestimate both the likelihood and potential impacts of rare but catastrophic events. (Lauren, 2023)

A similar effect can also be seen in the preparedness paradox, which states that the more effective risk management and protective measures are, the less people perceive the underlying hazard as a threat. Ironically stating that success can reduce public motivation to stay engaged in preparedness activities or support long-term mitigation strategies. (Demuth et al., 2016)

These psychological factors illustrate why integral risk communication must sustain long-term awareness and keep collective memory alive. Because communities that remember past events often take future risks more seriously and prepare more effectively. In Switzerland, this role has increasingly been recognized in exhibitions, cultural spaces, and public education initiatives.

The challenge is to move beyond commemoration to support both memory and preparedness. This raises questions about how visualization and immersive techniques can leverage the emotional power of memory while also enabling forward-looking engagement with risk scenarios and preparedness strategies.

## FRAMEWORK

Several frameworks offer guidance for addressing visualization limitations in hazard communication. The following approaches guided this thesis:

Environmental Data Visualization Framework (Grainger et al., 2016) proposes design principles for environmental data visualization in non-scientific contexts, emphasizing simplicity, local relevance, and narrative integration. It highlights the importance of moving beyond technical accuracy to create visualizations that resonate with public audiences through storytelling and personal connection.

User-Centered Design for Disaster Risk Visualization (Twomlow et al., 2022) advocates participatory engagement and iterative feedback in developing disaster risk visualizations. Emphasizes the importance of involving target audiences throughout the design process to ensure visualizations meet actual user needs rather than designer assumptions.

Critical Information Visualization (Dörk et al., 2013) stresses the need to question framing choices and underlying assumptions that shape data representation. It calls for transparency about the political and social dimensions of visualization design, emphasizing disclosure, plurality, and empowerment rather than false neutrality.

Risk Communication Guidelines (Höppner et al., 2010) outlines practical principles for hazard communication, including transparency, interactivity, and cultural adaptation. Emphasizes that effective communication depends on understanding local contexts and providing multiple pathways for engagement with risk information.

These frameworks collectively emphasize user-centered design, contextual relevance, critical reflection on design choices, and transparency.

## 5. VISUALIZING NATURAL HAZARDS

This chapter examines how visualization serves risk communication, the limitations of current approaches, and the opportunities for more contextual and spatially grounded approaches.

### 5.1. HOW VISUALIZATION SERVES RISK COMMUNICATION

Visualization has long played a central role in translating complex geodata about natural hazards into understandable forms. By making abstract risk information visible, visualizations enable stakeholders to forecast, assess risk levels, and make informed decisions (MacEachren, 2004).

The functions of hazard visualization directly support the risk communication purposes established in chapter 4.2.:

**Inform:** Hazard visualizations condense complex data into formats that can inform both expert and public audiences about hazard type, location, probability, and potential impacts. They bridge the gap between technical systems (hydrological models, seismic sensors) and public-facing awareness tools (Grainger et al., 2016).

**Enabling Trust-Building:** Visual representations of uncertainty can strengthen or undermine credibility depending on their design. When visualizations make their limitations and assumptions explicit, they support the transparency that effective risk communication requires.

**Facilitating Shared Understanding:** Maps and scenario visualizations can enable communication across different stakeholder groups. It creates common ground for dialogue about risk levels and management strategies.

In Switzerland, hazard visualization serves additional regulatory functions. Many hazard maps are legally binding documents that guide municipal zoning and building regulations, making visualization not only a communication tool but an instrument for enforcing protective measures and defining land-use restrictions (FOEN, 2020). Yet, despite this institutional commitment, the communicative impact of these visualizations is highly variable.

### 5.2. CURRENT APPROACHES AND THEIR LIMITATIONS

Switzerland maintains sophisticated hazard visualization systems ranging from static regulatory maps to interactive digital platforms. They reveal how communication strategies shift depending on whether the target audience is experts, decision-makers, or the general public.

#### 5.2.1. FORMS OF CURRENT VISUALIZATION

Static hazard maps remain the most used tool, produced at cantonal and municipal levels to delineate hazard zones such as floodplains, avalanche tracks, and rockfall corridors. While highly detailed and scientifically accurate, they are designed primarily for planners and engineers. For non-experts, color-coded

zones often lack the context needed to understand personal implications. (BAFU, 2025)

**Digital dashboards and interactive platforms** have become increasingly popular. Swiss platforms such as [map.geo.admin.ch](https://map.geo.admin.ch) or early-warning websites provide real-time data. These tools combine maps with layered information, allowing users to zoom in. While they offer transparency and inclusivity, they also require a higher level of data literacy and can overwhelm non-expert users with too many options (Hullman, 2020).

**Infographics and educational materials** illustrate hazards into more accessible formats like explanatory brochures and animations. While these lower the threshold for public understanding, they risk oversimplifying dynamic processes and may not address the locally specific concerns that drive individual preparedness decisions (Grainger et al., 2016).

**Exhibitions and installations** translate hazards into tangible, often immersive experiences. The Goldauer Erlebnishalle, for example, uses panoramic video to reconstruct the catastrophic rockfall from 1806. Such formats engage visitors emotionally and keep collective memory alive (Birkholz et al., 2014).

Taken together, these forms reveal the range of visualization practices. From the regulatory precision of hazard maps to the narrative and emotional resonance of exhibitions.

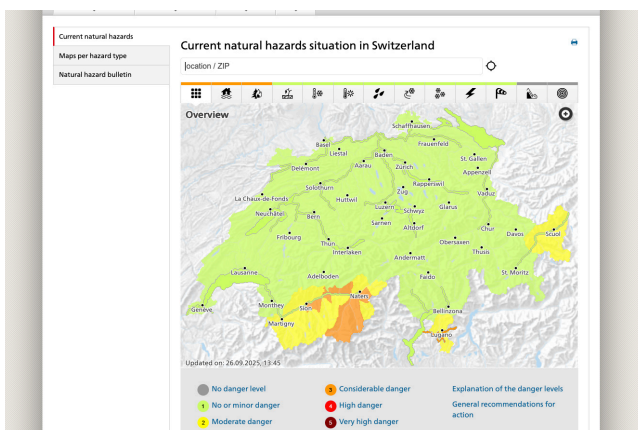


Fig. 9: Screenshot Natural Hazards Portal (FOEN, 2025); Fig. 10: Rockfall Simulation, Erlebnishalle Goldauer Bergsturz (Szenografie, 2024)

### 5.2.2. PERSISTENT LIMITATIONS

Despite institutional commitment to hazard mapping and public information, Swiss hazard visualization faces several challenges that limit effectiveness of communication:

**Accessability and literacy barriers:** Abstract data formats and generic classifications make it difficult for non-experts to interpret hazard information and understand personal implications. (Hullman, 2020).

**Design accessibility issues:** Visual conventions like symbols and color schemes that work for experts may irritate the communities they aim to inform.

**Uncertainty communication challenges:** Showing probability ranges can confuse people. On the other hand, when information gets oversimplified to avoid confusion, it can make people overconfident instead. (Lundgren & McMakin, 2009).

These limitations create a gap between the availability of high-quality hazard data in Switzerland and its actionability for the diverse publics who must ultimately prepare for and respond to risks. The challenge lies not in data quality or technical sophistication, but in the translation between expert knowledge systems and public understanding.

### 5.3. FROM CONVENTIONAL TO CONTEXTUAL VISUALIZATION

Conventional forms of hazard visualization (Chapter 5.2.1.), remain central to planning and communication. They make risks visible, but often at the cost of stripping them from their spatial context. As Grainger et al. (2016) states, environmental data visualization for non-scientific audiences is often expert-centric in design, which risks alienating or confusing the very groups it aims to inform. They highlight that successful visualization in this context must account for differing levels of data literacy, local relevance, and emotional engagement, moving beyond simply “showing the data” toward framing it in ways that align with audience needs and lived experience.

This connects to broader conversations about data representation and meaning-making. The concept of “warm data”, developed by Bateson, offers a useful perspective. Warm data refers to information that gains meaning through relationships, context, and interconnection rather than through isolation and abstraction. Unlike “cold data” that focuses on discrete measurements and classifications, warm data emphasizes the patterns and contexts that give information relevance. (IBI, 2025)

Applied to hazard visualization, this helps explain why technically accurate maps may fail to resonate with public audiences. Cold data approaches present hazards as red zones or probability percentages that require specialized knowledge to interpret. Warm data approaches would embed hazard information within the relational contexts that give it meaning.

This conceptual shift from cold to warm data representation points toward visualization approaches that prioritize contextual understanding over technical precision alone. Reconizing that effective risk communication depends not only on accurate data but on data that can be meaningfully interpreted within people's existing spatial and social frameworks.

The swisstopo prototype demonstrated one direction for this exploration. By making geodata browsing and exploration fun through haptic interaction, the prototype showed that embodied engagement could lower barriers to spatial information. Rather than requiring specialized knowledge to interpret abstract representations, users could discover and explore data through natural physical interaction. The positive response to these haptic dimensions suggested that such approaches could make complex spatial datasets more accessible to broader audiences.

This prototype experience, while limited in scope, pointed toward broader possibilities for hazard visualization. If geodata exploration can be made engaging and intuitive through physical interaction, similar approaches might address the accessibility challenges that conventional hazard visualizations face with non-expert audiences.

## PROTOTYPE



### SWISSTOPO PROTOTYPE

This prototype was developed during a two-week design sprint with swisstopo for their showroom, creating haptic exploration functions that allow users to physically search through and navigate Switzerland's comprehensive geodata. The tactile search capability enabled users to discover spatial information by gesture, drawing their way through different data layers and geographic features beyond traditional map-based representations.

User feedback revealed strong appeal of this embodied data interaction. Users can explore and discover spatial datasets through natural physical engagement, making complex geographic information more tangible and accessible.

The positive response pointed toward broader applications for hazard visualization. The project demonstrated institutional willingness to experiment with non-traditional data representation methods and provided practical foundation for developing spatially grounded communication approaches that could address accessibility challenges conventional hazard visualizations face with non-expert audiences.

## 6. MIXED REALITY

Mixed Reality (MR) technologies offer promising capabilities to complement existing visualization systems by enabling direct overlay of digital information onto physical environments and supporting embodied interaction with complex spatial data.

This chapter examines how MR technologies can serve as valuable addition to environmental risk communication, their affordances and the design considerations necessary for responsible implementation. It establishes the foundation for understanding how MR might work alongside established approaches to create more comprehensive hazard communication strategies in Switzerland.

### 6.1. DEFINING IMMERSIVE TECHNOLOGIES

Immersive technologies are defined as technologies that create a simulated experience perceived by the user as real, including Virtual Reality, Augmented Reality, and Mixed Reality (“Immersive Technologies”, 2025). These technologies are positioned along the “Reality-Virtuality (RV) Continuum” (Fig. 12), first introduced by Milgram and Kishino (1994), where physical reality sits at one end and fully virtual environments at the other.

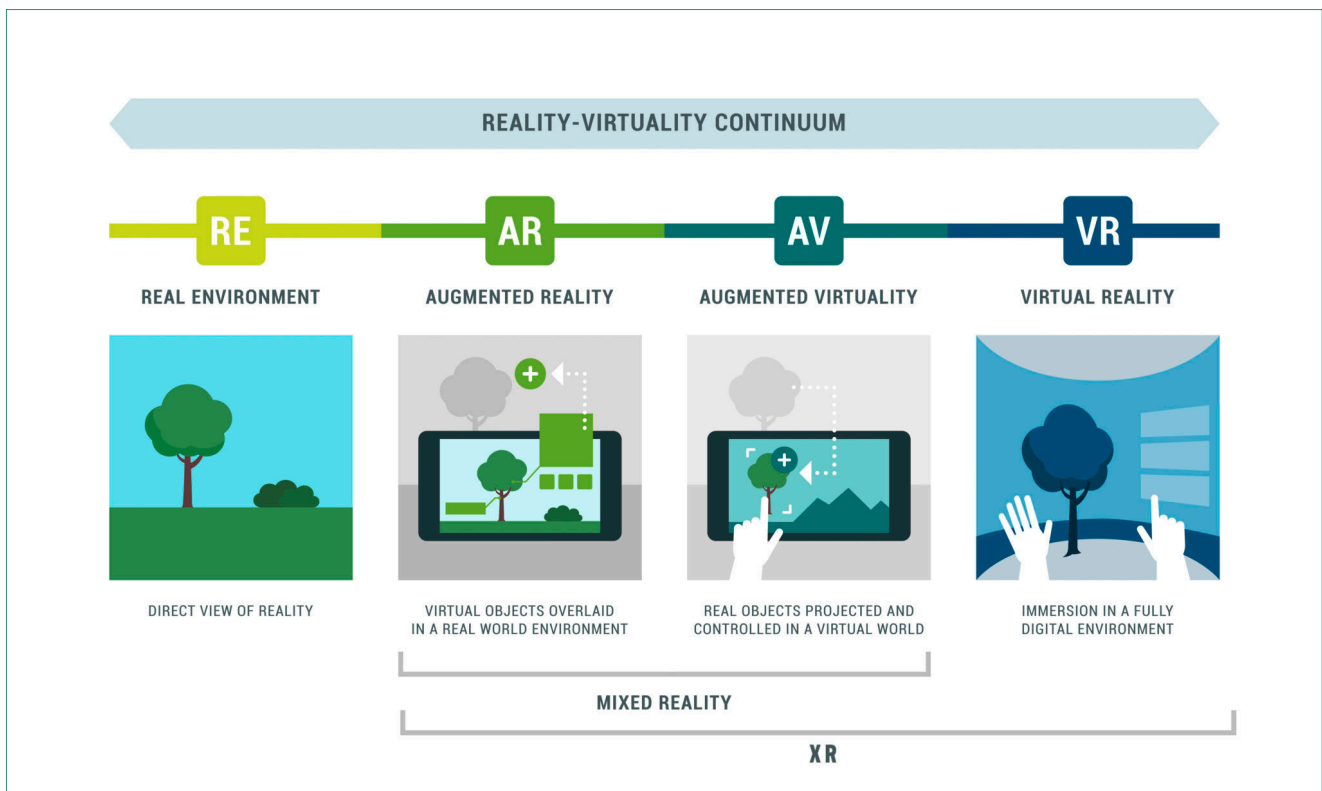


Fig. 12: Reality-Virtuality Continuum (Creatix,2021)

### 6.1.1. VIRTUAL REALITY

Virtual Reality (VR) immerses the user entirely in a computer-generated environment, effectively replacing their physical surroundings and creating a complete sense of presence in a synthetic environment. Users can explore and interact with that environment through specialized hardware, software and sensory synchronicity. It often includes auditory or haptic feedback to enhance presence. VR is shown on large screens, in special rooms (Cave Automatic Virtual Environment, or CAVE for short), or via a head-mounted display (HMD). VR is widely used in training, simulation, and education, providing fully immersive experiences. (“Virtuelle Realität”, 2025)

### 6.1.2. AUGMENTED REALITY

Augmented Reality (AR) enhances the physical world by overlaying digital information, such as visual elements, audio or other sensory stimulation. Users maintain connection to their physical reality while adding digital enhancements. (Rokhsaritalemi et al., 2020)

AR has been implemented across diverse sectors like archaeology, medicine, education, construction, and tourism.

### 6.1.3. MIXED REALITY

Mixed Reality (MR) represents the fusion of physical and digital worlds, enabling natural and intuitive three-dimensional interactions between humans, computers, and environments.

Even though MR is a broader category that includes AR, nowadays it is commonly differentiated from AR by its enhanced capability for interaction between real and virtual objects or worlds through gestures, voice, and movement (Rokhsaritalemi et al., 2020).

Mixed Reality (MR) environments are characterized by three key terms (Rokhsaritalemi et al., 2020):

- **Immersion** is the real-time processing of user environment. This is typically achieved without the use of external controllers, instead relying on natural input methods such as gestures, gaze, and voice.
- **Interaction** describes the user's ability to engage with both virtual and physical elements within the MR space.
- **Information** (or environment) relates to the spatial and temporal registration of virtual objects, allowing them to appear meaningfully anchored within the user's physical world.

MR display tools can be grouped into four types: head-mounted displays, hand-held devices, monitor-based systems, and projection-based displays. The effectiveness of these tools depends largely on two factors: user comfort (such as heat management) and the level of immersion (such as the field of view), both of which influence usability and the overall quality of experience.

In terms of visualization technology, MR environments typically use either optical see-through or video see-through systems. Optical see-through allows users

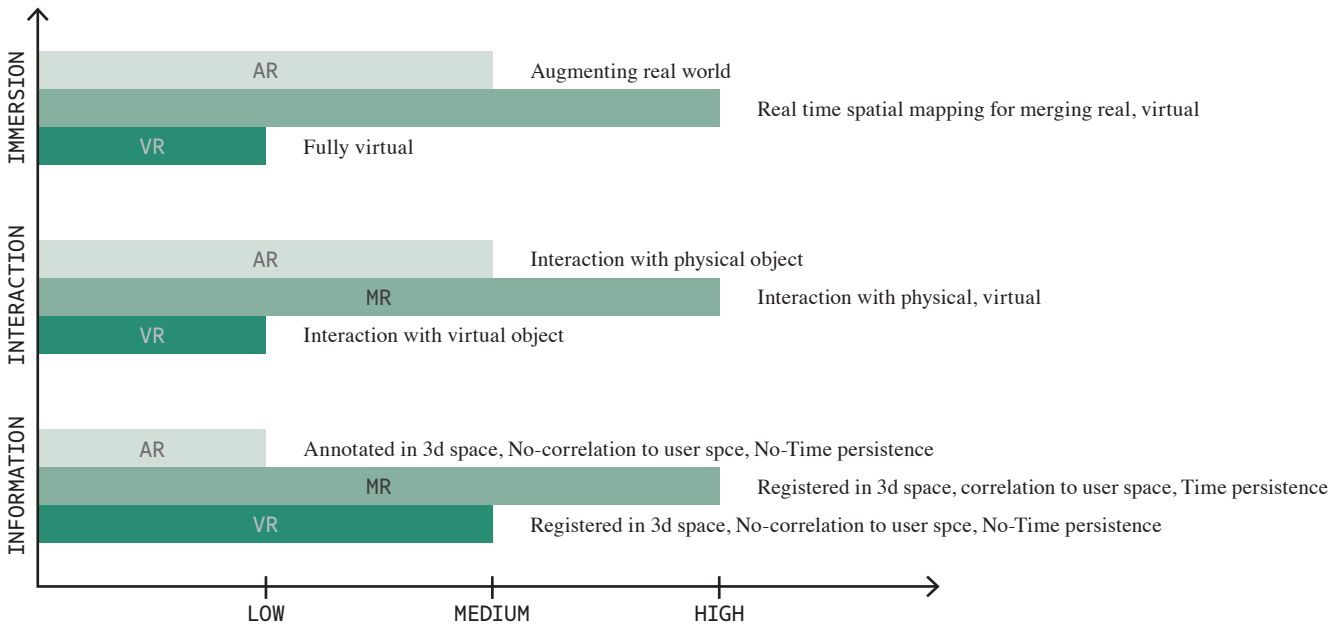


Fig.13: Comparison of three main characters. (Adapted from Rokhsaritalemi et al., 2020)

to view the real world directly through transparent displays, such as smart glasses. In contrast, video see-through systems present a combined view of real and virtual content on a display. (Rokhsaritalemi et al., 2020)

### 6.2. MR AFFORDANCES FOR ENVIRONMENTAL RISK COMMUNICATION

Mixed Reality offers several affordances that align particularly well with the needs of environmental risk communication, especially in addressing the visualization limitations identified in previous chapters.

#### Spatial Anchoring and Context Preservation

MR's capacity for context-aware overlays enables direct registration of hazard information onto physical environments. MR can present flood scenarios directly on actual streets, or landslide risks on visible slopes. This spatial anchoring addresses the limitation of conventional visualizations that strip hazard information from its spatial context.

#### Embodied Interaction and Natural Engagement

Research in embodied cognition demonstrates that people understand complex information more effectively when they can engage with it through physical interaction and spatial exploration (Johnson-Glenberg, 2018). MR enables users to “walk” around hazard scenarios and interact with them through natural gestures rather than abstract interfaces. This embodied engagement can lower barriers to complex information, making technical hazard data more accessible to non-expert audiences.

### Multi-perspective Visualization

MR supports viewing hazard scenarios from multiple perspectives, ground level, elevated viewpoints, or cross-sectional views, enabling users to build comprehensive mental models of how hazards might affect their environment.

### Collaborative Spatial Understanding

MR applications can support multiple users experiencing and discussing the same spatial information simultaneously.

These affordances position MR as particularly suitable for addressing the "warm data" challenge discussed in the visualization chapter, creating information experiences that gain meaning through spatial relationships and contextual understanding.

Billingham et al. (2015) notes that spatial computing enables users to move from "viewing" data to inhabiting it, offering new opportunities for engagement, reflection, and behavioral insight. This is further supported by Grainger et al. (2016), who argue that "narrative-based visualizations, especially when personalized or location-specific, have been shown to increase engagement and comprehension among general audiences." Their findings support the use of spatial, immersive technologies that align environmental data with people's lived experiences.

These insights highlight the potential of MR to support more accessible and embodied ways of learning about natural hazards. MR can bridge gaps in data literacy and make complex information more tangible.

## 6.3. DESIGN CONSIDERATIONS AND RESPONSIBLE IMPLEMENTATION

Responsible implementation requires careful attention to both technical limitations and ethical considerations.

### 6.3.1. TECHNICAL IMPLEMENTATION CHALLENGES

**Environmental Registration:** Outdoor environments present tracking and registration challenges compared to controlled indoor spaces. Maintaining accurate spatial alignment between virtual hazard information and physical features requires robust methods that function across varied lighting conditions and GPS limitations.

**Hardware Accessibility:** Current MR hardware remains expensive and requires technical literacy, potentially excluding people. Design approaches should consider parallel low-tech alternatives and plan for broader accessibility as technology develops.

**Content Development Complexity:** Creating accurate, locally relevant hazard scenarios requires technical expertise, designers, and stakeholder engagement. The complexity of this process may limit scalability but is essential for credibility and relevance.

These challenges lead to high content development cost, limited hardware accessibility and a requirement for robust technical infrastructure. (Rokhsaritalemi et al., 2020)

### **6.3.2. ETHICAL AND PSYCHOLOGICAL CONSIDERATIONS**

Immersive risk communication can produce unintended psychological effects that must be carefully managed. Research documents mixed outcomes from VR disaster simulations - while some users become more cautious, others develop overconfidence or reduced perceived urgency (Bernhardt, 2019). Repeated exposure can lead to habituation effects that diminish impact over time (Jiuyi et al., 2024). Additionally, cybersickness affects up to two-thirds of VR users, potentially excluding vulnerable populations (Stanney et al., 2021).

These concerns highlight the need for design approaches that prioritize user agency and constructive action over dramatic simulation. Rather than creating anxiety without empowerment, applications should connect risk understanding to specific preparedness actions while emphasizing individual and collective capacity for risk reduction.

These concerns highlight the importance of responsible design practices, which are integrated into the guidelines developed later in this thesis.

## PROTOTYPE



### LOW-FIDELITY FLOOD SIMULATION

Early explorations in mixed reality visualization of flood scenarios tested the potential for contextual anchoring of hazard information within familiar spatial environments. The low-fidelity MR implementation used basic overlay techniques to visualize rising water levels.

Users could observe flood progression in their own basement and walk around affected areas to view impacts from multiple angles. The prototype enabled simple navigation through flooded environments and examination of how water would affect specific locations of personal relevance.

The prototype demonstrated potential for contextual anchoring of hazard information within familiar spatial environments, showing how MR could make abstract risk zones more tangible and personally meaningful. However, technical constraints including registration challenges in outdoor environments and simplified flood modeling limited realism and required controlled conditions. The exploration remained at proof-of-concept stage without systematic user evaluation, highlighting both the promise and technical challenges of spatially grounded hazard communication approaches.

Fig. 14: Screenshots Video Recording Flood Prototype (Author's own images)

## 7. SPATIALLY INTUITIVE COMMUNICATION

The idea of **spatially intuitive communication** is based on synthesized insights from the previous chapters of this thesis.

As discussed in chapter 3 on Natural Hazards in Switzerland, risks are not limited to a few exposed regions but remain highly localized, and challenges are increasing due to factors such as climate change and urbanization. Switzerland's rich geospatial data infrastructure makes location-based communication possible. As natural hazards are considered a shared responsibility, a shared vocabulary is necessary.

The chapter on Environmental Risk Communication shows that the purpose of environmental risk communication goes beyond the linear communication model of only transferring information. It aims to inform and educate, to motivate protective action, and to build trust between institutions and the public. Research demonstrates that transparency, local relevance, and participation increase trust and uptake (Höppner et al., 2010; Lundgren & McMakin, 2009), with spatial anchoring directly supporting these aims by connecting abstract risks to familiar places. At the same time, communication has a relational function: it enables a shared understanding of risk and supports the collective responsibility that underpins Switzerland's approach to natural hazards.

Achieving this is difficult. Complexity, perception gaps, diverging viewpoints, uncertainty, fragile trust and memory all shape how messages are received. Effective risk communication therefore functions as a continuous social process rather than a purely technical exercise (Lundgren & McMakin, 2009).

The discussion of Visualizing Natural Hazards in chapter 5 showed how conventional visualization tools are important but often remain inaccessible to non-expert audiences. Grainger et al. (2016) show that narrative and visual storytelling approaches, particularly location-specific visualizations, can make environmental information more relatable, while Hullman (2020) and Dörk et al. (2018) emphasize that visualizations must also support critical engagement rather than passive consumption. The research states that conventional visualization can increase awareness and comprehension, but it often struggles to connect abstract data to lived experience. This limitation indicates the potential of immersive and contextual approaches that bridge the gap between abstract data representation and embodied understanding.

Finally, the chapter on Immersive Technologies and Mixed Reality demonstrated how immersion, interaction and environment can enhance comprehension of complex, multidimensional information. Studies on embodied VR learning show improved conceptual understanding in spatial domains (Johnson-Glenberg, 2018), while TUI research demonstrates that physical interaction can lower barriers to complex systems. These findings highlight how exploratory, hands-on engagement supports active meaning-making among non-experts. Within the geospatial domain, scholars such as Billingham et al. (2015) and Rokhsaritalemi et al. (2020) have documented the value of overlaying geodata onto physical environ-

ments, enabling users to directly connect datasets with the spaces they inhabit.

Prototypes like the one for *swisstopo* suggest a growing institutional interest in such approaches, while pilot projects like *RaR* emphasize the importance of shared vocabulary and participatory sense-making.

This synthesis demonstrates that while Switzerland has strong data infrastructures and established traditions in risk management, the connection between technical knowledge and everyday experience remains fragile. Traditional tools often struggle to resonate with non-expert audiences, not because the data are insufficient, but because the formats are abstract, hard to translate into personal relevance.

To address this gap, this thesis proposes the concept of spatially intuitive communication. The term is introduced as a new design approach that builds on the foundations of risk communication, visualization, and mixed reality, while emphasizing the role of environment and embodiment in how people engage with natural hazard information. The following section will define this concept more precisely and outline how it can guide the design and evaluation of future communication tools.

## 7.1. DEFINITION

Spatially intuitive communication is defined as a design approach that applies people's natural spatial understanding and embodied experience to make complex information more accessible and personally relevant. This approach addresses the persistent challenge of translating abstract technical data into formats that resonate with non-expert audiences in their lived environments. Much of this disconnect arises because three-dimensional environmental processes are routinely flattened into two-dimensional data formats during collection and storage, losing the spatial context that people need to understand how these processes might affect their lived spaces. Unlike conventional communication methods that rely primarily on symbolic interpretation or specialized knowledge, spatially intuitive communication works with the spatial reasoning abilities that people use naturally to navigate and understand their world.

### 7.1.1. CORE CHARACTERISTICS

The concept rests on four foundational characteristics that distinguish it from traditional approaches to information design:

**Spatial grounding** refers to anchoring information within physical locations or spatial relationships that audiences can directly relate to. Rather than presenting data as abstract statistics or generalized maps, spatially grounded communication connects information to specific places people know, for example their neighborhood, their daily routes, or familiar landmarks. This transforms remote data into situated knowledge.

**Intuitive engagement** means designing interactions that work with how people naturally process spatial information through movement, visual-spatial memory, and embodied experience. Instead of requiring users to learn new symbolic systems or technical vocabularies, intuitive engagement taps into existing spatial competencies such as perspective-taking, distance estimation, and three-dimensional reasoning.

**Contextual relevance** ensures that information is presented within the spatial context where it becomes meaningful and actionable. This goes beyond simple location-awareness to consider how people experience and move through spaces, what spatial relationships matter to them, and how their understanding of place influences their interpretation of information. In mixed reality applications, this translates to context-aware overlays that adapt information presentation based on user location, environmental conditions, and situational relevance.

**Embodied interaction** enables people to engage with information through natural behaviors: looking around, moving through space, manipulating objects, or exploring from different viewpoints. This physical engagement supports active meaning-making and helps bridge the gap between abstract data and personal understanding.

However, spatially intuitive communication differs from existing approaches by explicitly using spatial dimensions to formation. By placing that information in situ within the environments where it becomes relevant, it offers a distinct alternative to conventional communication methods.

While spatially intuitive communication could be realized through various media, mixed reality technologies offer particularly promising affordances for this approach. MR's capacity for context-aware overlays enables the direct registration of information onto physical environments, while its support for embodied interaction allows users to engage with data through natural gestures. Recent advances in computing power and cloud storage also make accessing comprehensive geodata across Switzerland's territory increasingly feasible for MR applications. Given this thesis's research focus on mixed reality applications for natural hazard communication, MR technologies receive particular attention in the design guidelines that follow.

## 7.2. APPLICATION TO NATURAL HAZARD COMMUNICATION

In the context of natural hazards, spatially intuitive communication addresses specific challenges that conventional approaches struggle to resolve. Traditional hazard maps and warning systems often fail to connect with public understanding because they present risks as abstract zones or statistical probabilities rather than as threats to specific places that matter to people. Spatially intuitive communication would instead enable people to explore hazard scenarios within the spatial contexts they inhabit like their homes, their communities, their daily landscapes. In practice, this might mean overlaying flood risk data directly onto the streets people walk daily or allowing someone to physically manipulate a

3D model of their valley to understand landslide scenarios. The "intuitive" part comes from tapping into spatial reasoning skills everyone already has, while the "spatial" part grounds abstract risks in concrete, familiar places.

When individuals assess whether they might be affected by flooding, landslides, or other hazards, they think in terms of familiar spatial relationships: how water flows through their valley, which slopes appear unstable, or how their building relates to nearby infrastructure. Spatially intuitive communication tools would support and enhance the spatial reasoning rather than requiring people to translate between abstract representations and their environment.

The concept provides guidance for designing communication tools that can strengthen both individual preparedness and collective responsibility. By grounding hazard information in shared spatial experiences, these tools can support the development of common vocabularies and shared understanding that effective risk governance requires.

# 8. DESIGN GUIDELINES FOR MIXED REALITY APPLICATIONS

The following guidelines translate the four characteristics of spatially intuitive communication into practical recommendations to design mixed reality applications for natural hazard communication. Each guideline directly addresses specific challenge or limitation identified in earlier chapters.

	GUIDELINE	CHALLENGE	IMPLEMENTATION CONSIDERATIONS	UX INDICATORS	EFFECTIVENESS QUESTION
SPATIAL GROUNDEDING	Anchor Data Precisely	Limited personal relevance and environmental challenges	Use high-accuracy GPS with visual-inertial tracking, implement SLAM for GPS-denied areas, maintain persistent anchor points across lighting conditions.	Can users identify locations immediately? Do virtual elements remain stable during movement and environmental changes?	Do users connect risk information to their lived environment without technical distractions?
	Show Human-Scale Comparisons	Abstract magnitude interpretation challenges	Show hazard magnitudes using human-scale comparisons, for example water depth relative to doorways, debris size compared to cars, wind force against walking.	Do hazard magnitudes feel tangible rather than abstract? Can users relate measurements to familiar objects?	Do users better understand personal implications of hazard intensities?
	Support Multi-Scale Spatial Navigation	Hyper-local variability vs. regional patterns	Enable smooth transitions between human-scale detail and regional overview through gesture or voice control.	Can users navigate between scales intuitively? Are spatial relationships preserved across scales?	Do users understand how local risks connect to broader patterns?
INTUITIVE ENGAGEMENT	Design for Recognition	Cognitive and literacy barriers	Use visual metaphors and symbols people already understand. Avoid requiring legend learning or symbol interpretation.	Do users understand visual elements without explanation? Are hazard indicators immediately recognizable?	Do users interpret risk information correctly without training?
	Use Gesture Recognition	Cognitive and literacy barriers	Use pointing, reaching, and walking as primary interactions. Avoid abstract gesture vocabularies requiring training.	Do gestures feel natural and responsive? Can users interact without conscious effort?	Do users explore content immediately without instruction?
	Support Exploration	Abstract data interpretation barriers	Design information revelation that rewards natural curiosity.	Do users naturally discover information through movement? Does exploration feel rewarding rather than confusing?	Do users learn about hazards through self-directed discovery?
	Optimize for Head-Mounted Display Limitations	Hardware accessibility constraints	Design for limited field of view, account for vergence-accommodation conflict, minimize text density.	Are interface elements within comfortable viewing range? Can users read information without eye strain?	Do users focus on spatial understanding rather than interface adaptation?
	Implement Cross-Modal Information Delivery	Design accessibility issues	Integrate spatial audio cues, haptic feedback for material properties, and visual indicators. Ensure redundancy across modalities.	Can users access key information through multiple senses? Does haptic feedback enhance spatial understanding?	Do users with different abilities access equivalent insights?

	GUIDELINE	CHALLENGE	IMPLEMENTATION CONSIDERATIONS	UX INDICATORS	EFFECTIVENESS QUESTION
CONTEXTUAL RELEVANCE	Visualize Uncertainty Through Spatial Probability	Uncertainty communication challenges	Show probability distributions as spatial gradients, use animation to indicate confidence ranges, provide scenario comparison.	Do uncertainty visualizations feel intuitive rather than technical? Can users understand confidence levels spatially?	Do users make better-informed decisions about local risks?
	Enable Real-Time Scenario Manipulation	Limited agency in preparedness	Allow parameter adjustment through direct manipulation, show immediate spatial consequences, enable before/after comparison.	Can users modify conditions and see results instantly? Do changes feel causally connected?	Do users develop actionable preparedness insights?
	Provide Context-Aware Information Triggering	Gap between technical and local knowledge	Use location-based triggers, activity recognition, and temporal relevance to present information during decision-making moments.	Does information appear when relevant to user activities? Are triggers non-intrusive?	Do users apply insights to real-world planning?
EMBODIED INTERACTION	Design for Comfortable Session Management	Cybersickness and accessibility	Limit sessions to 10-15 minutes, provide teleportation alternatives, allow adjustment of movement sensitivity.	Do users remain comfortable throughout sessions? Are motion options adjustable?	Can diverse users complete meaningful spatial exploration?
	Connect to Constructive Risk Responses	Risk of emotional manipulation	Present preparedness actions alongside risk visualization, emphasize protective measures and community resources.	Do users feel empowered after experiences? Are next steps clear and actionable?	Do users take concrete preparedness actions?
	Support Collaborative Spatial Experiences	Shared responsibility model requirements	Enable shared virtual spaces, synchronized viewing, and collaborative annotation tools for group decision-making.	Can multiple users share spatial understanding? Do groups engage in meaningful discussion?	Does collaborative use improve community risk dialogue?
CROSS-CUTTING	Implement Progressive Disclosure Architecture	Information overload in complex datasets	Layer information complexity, allow user-controlled depth of detail, provide contextual help without overwhelming interface.	Can users access appropriate detail levels? Does complexity increase manageable?	Do users engage with content at their comfort level?
	Ensure Graceful Degradation	Technical reliability in field conditions	Design fallback modes for reduced tracking, provide smartphone alternatives, maintain core functionality under constraints.	Does system remain usable when conditions are suboptimal? Are alternatives accessible?	Can essential spatial insights be communicated across technical conditions?
	Maintain Data Source Transparency	Trust issues in risk communication	Make data sources, update frequencies, and model limitations explorable within the MR environment through spatial UI elements.	Can users easily access source information? Are limitations clearly communicated?	Do users understand and trust the information basis?
	Plan for Iterative Stakeholder Integration	Need for shared vocabularies	Build feedback mechanisms into MR experiences, enable local content customization, support community-driven scenario development.	Do local stakeholders find spatial representations meaningful? Can community knowledge be integrated?	Does the system support actual community risk discussions?

### Technical Implementation Notes

- **Spatial Accuracy:** Outdoor tracking is difficult. Applications need GPS, camera tracking, and stable reference points to anchor hazard data precisely to real locations.
- **Hardware Limits:** Current headsets have narrow fields of view and comfort issues. Design within these constraints rather than fighting them.
- **Multi-User Setup:** Group discussions require synchronized content across multiple devices sharing the same spatial reference frame.
- **Computing Power:** Processing complex hazard simulations, real-time tracking, and high-quality rendering simultaneously demands significant computational resources that current mobile hardware struggles to provide.

These technical realities shape design decisions and inform the evaluation for spatially intuitive hazard communication.

## 9. CONCLUSION

Switzerland's natural hazards are becoming increasingly complex and unpredictable. At the same time, the country has developed sophisticated systems for natural hazard monitoring and risk management, from detailed hazard mapping to participatory projects like RaR. As new immersive technologies become available, opportunities emerge to complement these established approaches with tools that can make environmental data more spatially accessible to non-expert audiences. This thesis emerged from considering how MR might help translate three-dimensional environmental processes into more intuitive, spatially grounded understanding, therefore leading to the development of spatially intuitive communication as a design approach. This thesis has identified and addressed this gap through the development of spatially intuitive communication as a design approach for natural hazard information.

### 9.1. CORE CONTRIBUTION: SPATIALLY INTUITIVE COMMUNICATION

This research makes both a conceptual and practical contribution to risk communication. It introduces spatially intuitive communication as a design approach that uses spatial dimension to make environmental data more tangible and accessible. This differs from existing approaches that focus primarily on message framing (risk communication), graphical representation (traditional information design), or technical capability (mixed reality research). The approach centers on how people's embodied relationship with space can serve as a foundation for understanding complex information. By placing that information in situ within the environments where it becomes relevant, it offers a distinct alternative to conventional communication methods.

The four core characteristics (spatial grounding, intuitive engagement, contextual relevance, and embodied interaction) provide a foundation for design guidelines that bridge technical precision with human spatial understanding. This is not merely about making data “more visual” but about fundamentally recontextualizing information within familiar environments.

### 9.2. PRACTICAL GUIDELINES FOR IMPLEMENTATION

The thesis translates this conceptual approach into design guidelines for mixed reality applications, organized around the four core characteristics. These guidelines address real implementation challenges: from maintaining spatial accuracy at human scale, to designing for accessibility and avoiding sensationalism. The evaluation tool provides a practical method for assessing how well applications embody spatially intuitive communication principles, emphasizing qualitative improvement over quantitative scoring.

Importantly, these guidelines do not propose replacing existing risk communication tools but rather complementing them. Mixed reality's affordances align particularly well with the needs of spatially intuitive communication, making it a natural medium for exploration while keeping the broader concept applicable across media.

### 9.3. SWISS CONTEXT AND RELEVANCE

This research focuses on Switzerland as the local context for investigation, and it proves particularly relevant to Switzerland's risk management paradigm, which emphasizes shared responsibility. This makes the topic urgent: if collective preparedness depends on shared understanding, then tools that can create common vocabularies and enable exploratory engagement with risk scenarios become essential.

The research also acknowledges Switzerland's rich geodata infrastructure and institutional commitment to transparency while recognizing that data availability does not automatically translate to public understanding. By focusing on recontextualization rather than data collection, the approach works with existing institutional strengths while addressing gaps.

### 9.4. IMPLICATIONS AND FUTURE DIRECTIONS

For design practice, this research shows how spatial and embodied approaches can make environmental data more accessible without sacrificing accuracy. The emphasis on local anchoring, scenario exploration, and natural interaction provides concrete directions for designers working at the intersection of data visualization and immersive media.

For institutions involved in risk communication, the work suggests hypotheses for future testing: that even modest steps toward spatial contextualization, such as anchoring information to recognizable landmarks or supporting “what if” exploration, might improve public engagement. The guidelines emphasize iterative stakeholder testing, ensuring that innovations serve rather than exclude vulnerable populations.

For research, spatially intuitive communication opens new questions about how immersive technologies reshape risk understanding and action. Future work could explore applications beyond natural hazards to climate adaptation, urban planning, or environmental decision-making more broadly. Something like collaborative mixed reality environments that enable multiple users to explore and discuss risks together represent a particularly promising direction.

### 9.5. LIMITATIONS AND ETHICAL CONSIDERATIONS

This thesis is primarily conceptual and design-oriented. Empirical validation through user testing and longitudinal studies remains essential future work. The guidelines proposed here require testing with diverse stakeholder groups.

Mixed reality's accessibility challenges, from hardware costs to cybersickness susceptibility, highlight the importance of future research into how spatially intuitive communication could be adapted across different media and interaction modes to ensure broader accessibility.

The thesis also acknowledges challenges of immersive risk communication. The design guidelines explicitly address these concerns through principles like designing for agency rather than fear and supporting short, comfortable sessions.

### 9.6. FINAL REFLECTION

Natural hazards in Switzerland are intensifying, but they are not only technical challenges, they are communicative ones. Risk communication can benefit from expanding linear communication models toward interactive experiences. This thesis contributes to this by proposing spatially intuitive communication as a bridge between environmental data and peoples environment.

Switzerland's commitment to shared responsibility in risk management creates an opportunity for communication tools that truly enable shared understanding. By making risks more tangible and situating them within familiar contexts, spatially intuitive communication approaches can support the collective preparedness that Switzerland's changing risk landscape demands.

This research represents one step toward risk communication that is not only scientifically accurate but also humanly meaningful. Connecting to the places where people live, work, and make decisions about their safety and that of their communities.

## **ACKNOWLEDGMENTS**

I thank my supervisor Karin Fink for their guidance and feedback throughout this research.

Thanks to my fellow students and friends for their support and patience during the writing process.

## **PART 2: DOCUMENTATION & REFLECTION**

While Part 1 developed the theoretical framework of Spatially Intuitive Communication and proposed design guidelines for MR applications, Part 2 documents the practical exploration of the project during, but mostly after writing Part 1 through a series of design experiments and prototypes. The final chapter reflects on how the ideas from Part 1 developed through making. The project evolved through multiple iterations, gradually refining the role of interaction and spatial context in communicating environmental data.

## 10. DOCUMENTATION

This chapter will show my design process throughout this thesis, beginning from the initial project that sparked the whole idea to a final prototype that serves as proof of concept in the context of spatially intuitive communication. Three different phases of this design process will be introduced by a short project description, followed by visual documentation.

### 10.1 Swisstopo Design Sprint

The Connect project with swisstopo (Federal Office of Topography) marks the real beginning of this work. For the design sprint, a small group of students were tasked to create concepts for a new AR experience for their GeoLab exhibition room in Bern. The goal was to make their work and by extension geodata tangible for the visitors.

I developed two concepts that approached geodata as a spatial experience rather than a map interface.

The first concept was about haptically searching through swisstopo's geodata. Instead of navigating data through search fields and layers, users could explore it directly in MR through haptical movement.

The second idea was about stepping into a point cloud landscape and snapping a selfie, while being surrounded by geodata. Using the snapshot as a souvenir postcard they could take home and maybe even use it as a conversation starter at home.

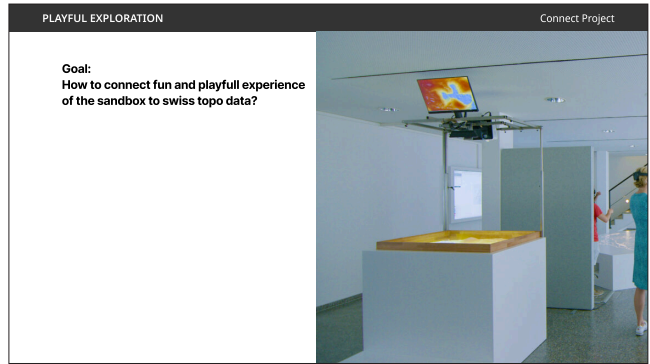
I still value the playfulness of these concepts. Their greatest potential lay in sparking curiosity and encouraging people to explore geodata for themselves.

This project furthermore introduced ideas that continued to appear throughout later prototypes. One was haptic exploration as a way of engaging with information. Another was the idea that data can become something people experience rather than simply observe.

# Documentation

## PLAYFUL EXPLORATION

By Sofia Camprubi and Silvan Monteiro

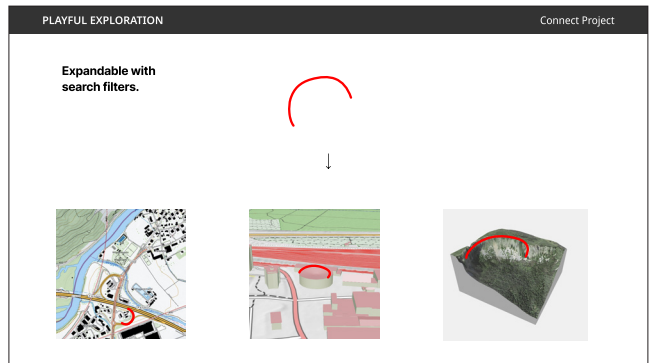
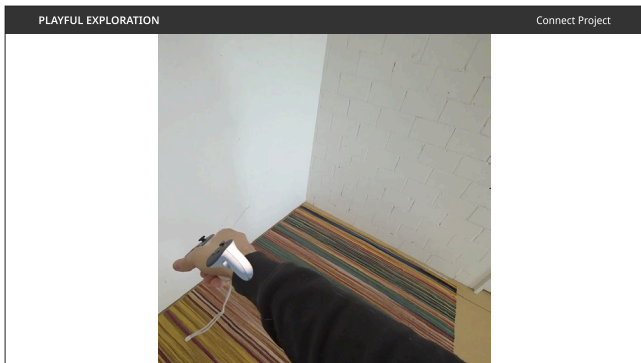
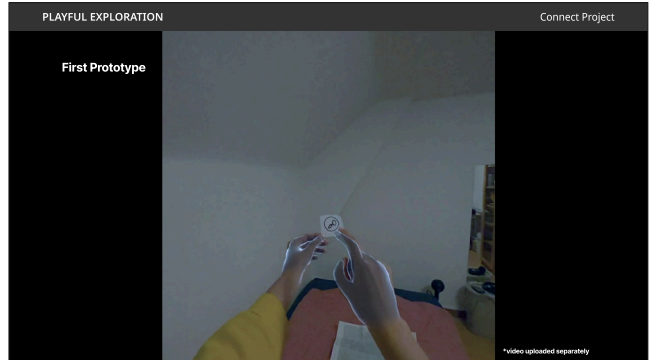


PLAYFUL EXPLORATION Connect Project

**Idea 1:**  
Haptic / 3d search function based on similarity.

An algorithm compares a 3d line you draw in virtual space with the geodata and shows you a "landscape" tile that resembles your line.

Adding filters allows exploring for example streets, objects or heights.



PLAYFUL EXPLORATION Connect Project

**Idea 2:**  
Collaborative Virtual Sandbox

Work together as a group to create your own virtual landscape (3D modeling) and see which Swiss landscape it resembles the most.

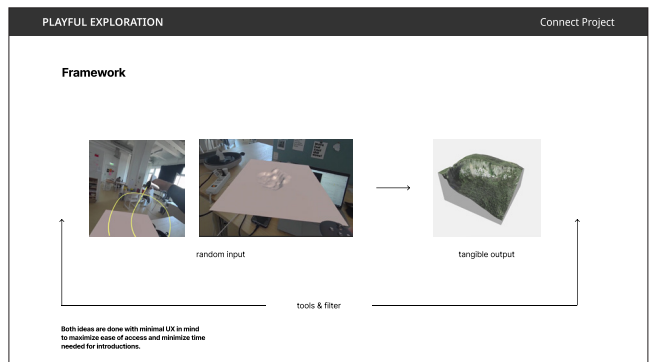
This way data can be explored in a experimental and easy way alone or in a group.



PLAYFUL EXPLORATION Connect Project

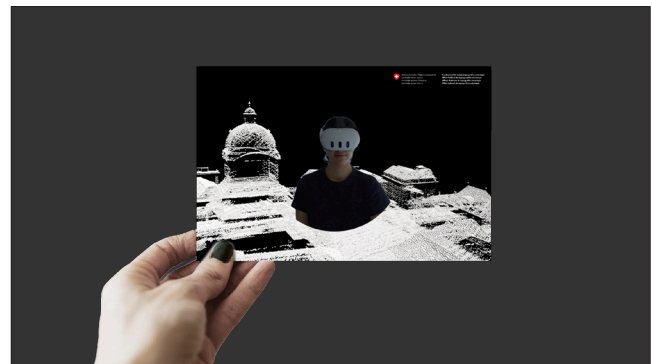
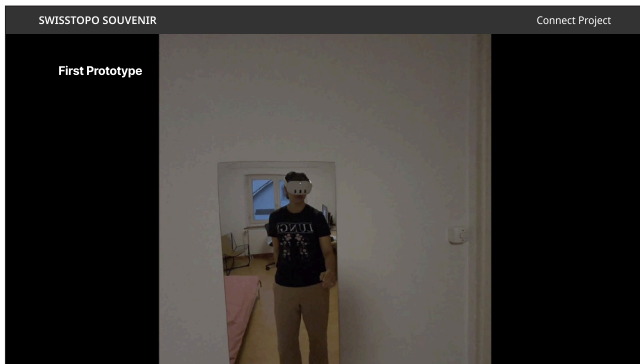
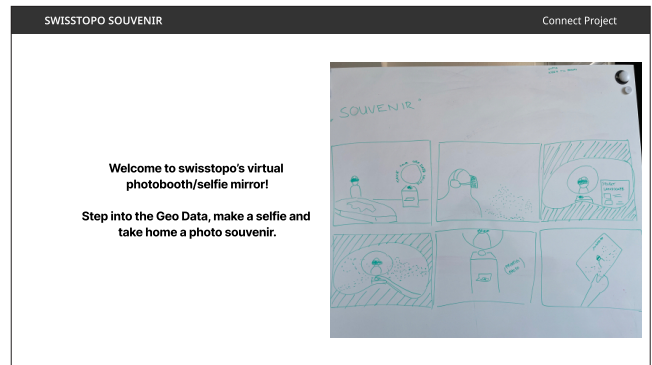
**Expandable with tools to create different characteristics.**

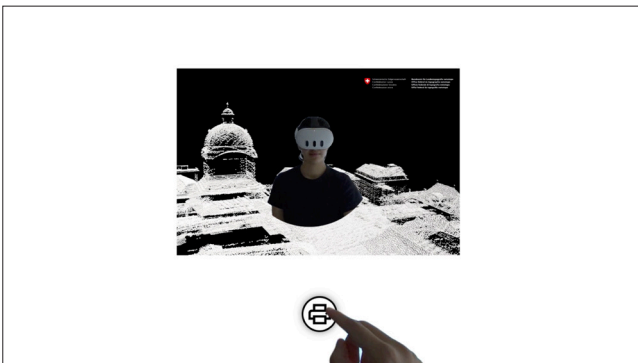
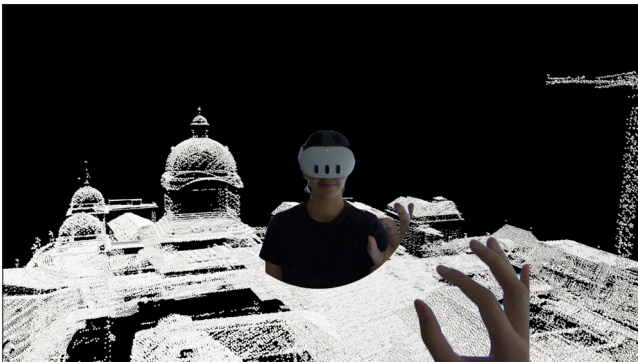
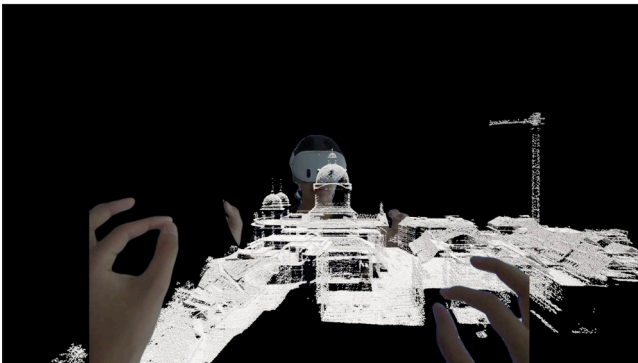
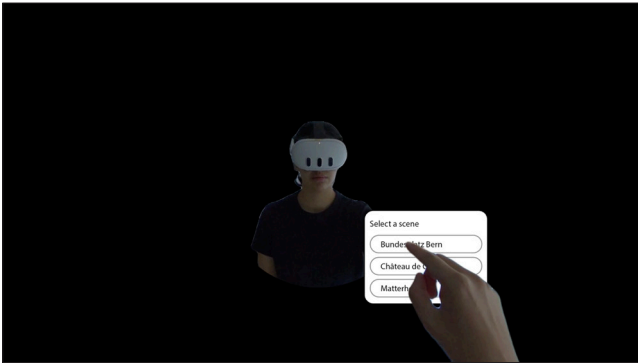
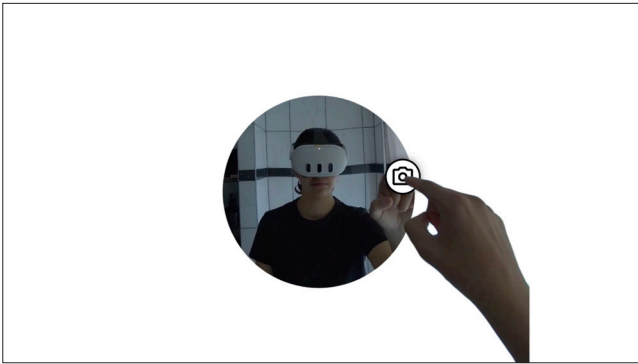
After some time, a piece of a 3D Swisstopo map will be projected onto the scene depending on the created terrain.



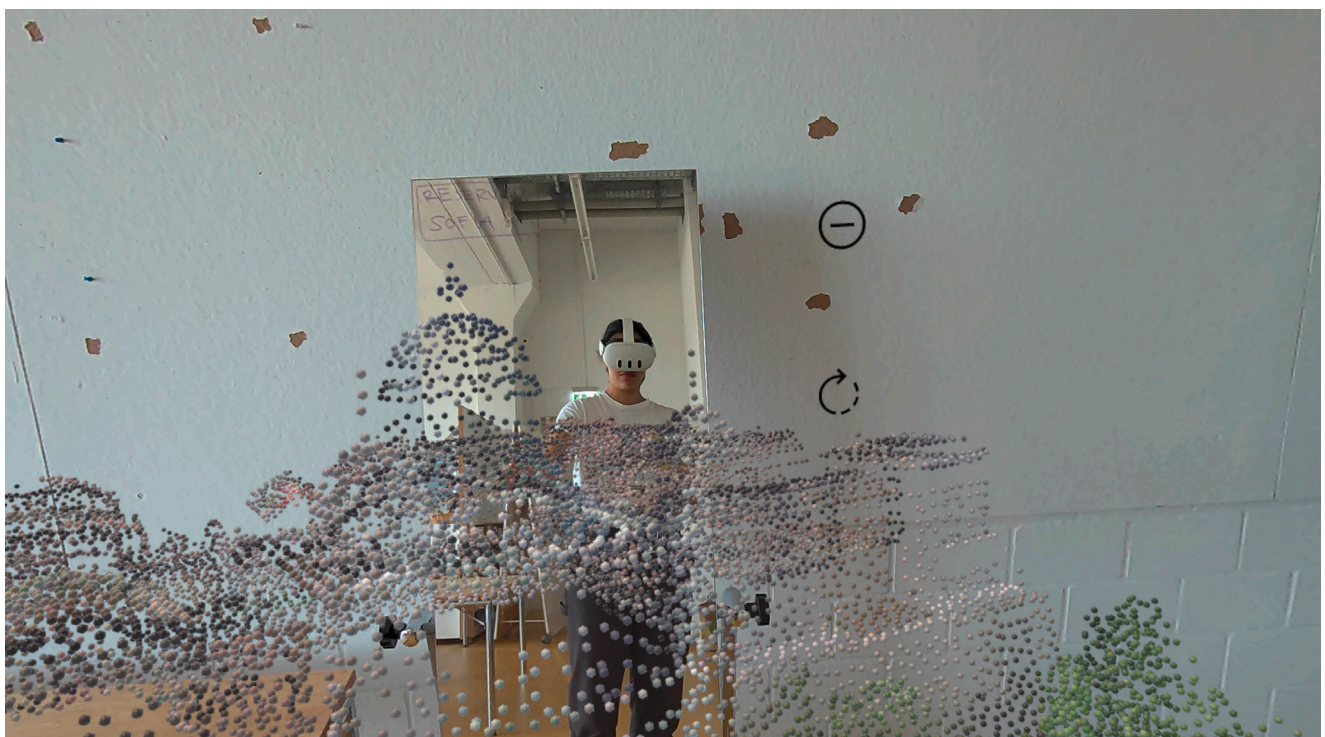
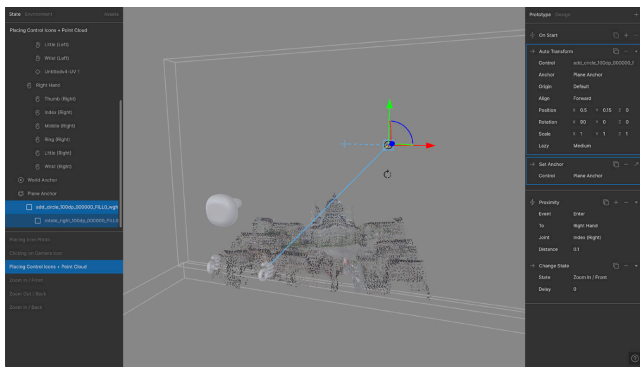


Screenshots of haptical exploration.





Screenshots of video prototype for swisstopo. Selfie concept.



Continuation of the selfie prototype. Point cloud in color.

## 10.2 Embodied Spatial Data Interaction

This phase was mainly experimental and explored how people might interact with spatial data in MR.

Before looking at existing MR interaction conventions, I recorded my own movements while imagining different interactions with the landscape and potential data overlays. The goal was not to design gestures but to observe which movements felt intuitive.

How could I navigate through information?

How could I manipulate something that exists as part of the environment rather than inside an interface?

The recordings revealed recurring patterns and intentions.

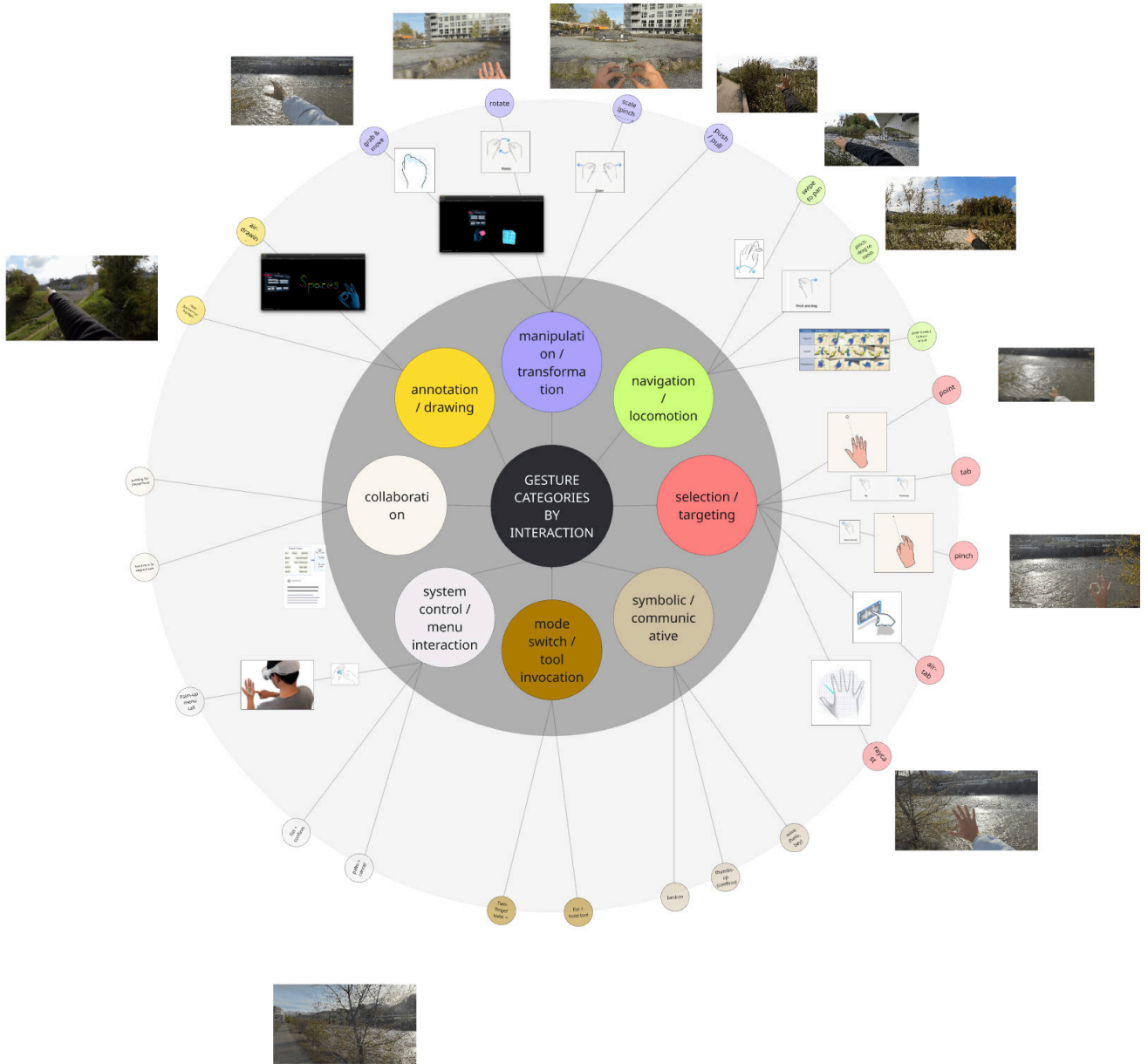
Afterwards, I analysed common MR gesture conventions and organised them into a gesture taxonomy based on their intended function. This taxonomy provided a framework for comparing established interaction patterns with my recorded movements. By mapping my own gestures onto these categories, it became possible to identify where intuitive movements aligned with existing conventions and where they suggested alternative ways of interacting with your surroundings.

The findings were then explored through a series of video prototypes. Using first-person recordings and simple visual effects, I investigated how spatial data and bodily movement could become part of the same experience. The video prototypes suggested ways in which bodily movement could become a means of navigating and interacting with spatial data.

Rather than developing a new gesture language, this phase was about understanding the relationship between movement, intention, and information in MR. The experiments explored interaction as a form of discovery rather than control.

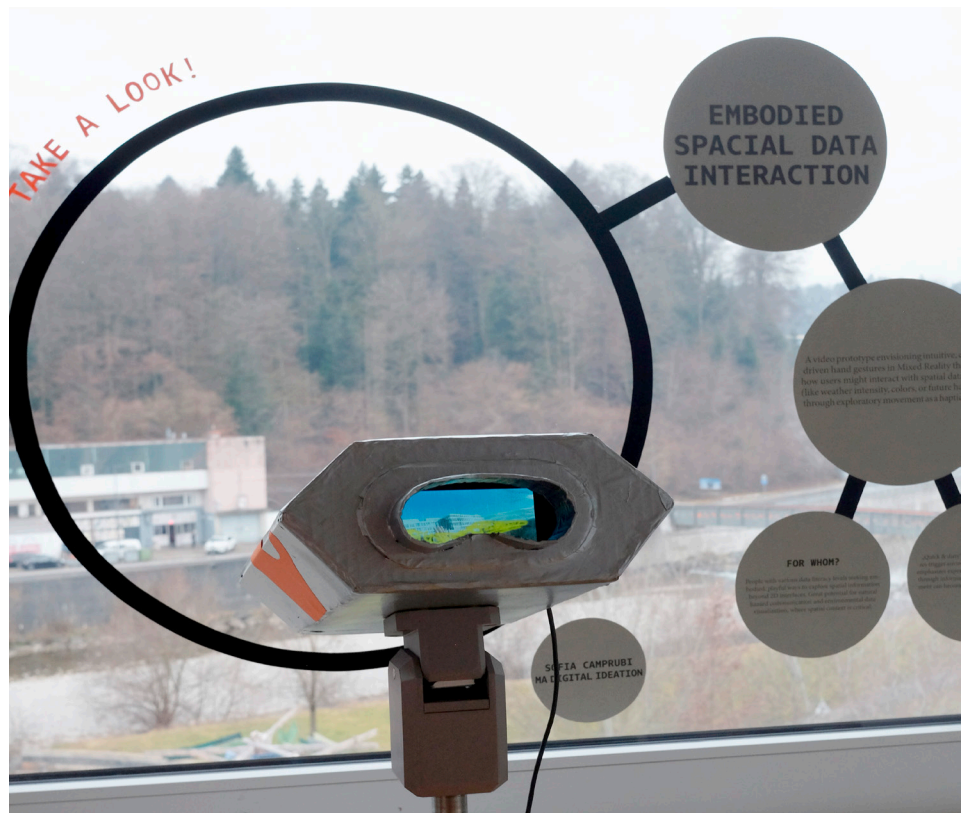


Screenshots of example movement. Exploring intuitive gestures.





Example video prototype of speculative interactions.



Exhibition Prototyping Module 3. Videoprototype playing in a "panoramic binocular".

### 10.3. Embodied Data through Simulation

The gesture experiments were accompanied by a broader ideation phase that produced numerous storyboards and speculative concepts. Some focused on interaction, while others explored how environmental information itself could be experienced in space. The ideas that felt most convincing were often not those with the most elaborate interactions, but those that made otherwise invisible processes visible.

This observation gradually shifted the direction of the project. Earlier concepts were strongly focused on interaction and exploratory discovery. While these ideas often felt engaging and playful, they also revealed a recurring challenge. The more attention users had to dedicate to learning an interaction, the less attention remained for understanding the information itself.

At the same time, many storyboard concepts relied on simulation. Rather than representing data as a static layer, they attempted to reveal relationships, consequences, and changes over time. This became increasingly interesting throughout development. Environmental processes are often difficult to understand because of the many factors that can influence one single event. Simulation offered a way to make these processes visible and easier to discuss.

The ideation phase eventually led to the development of two proof-of-concept scenarios. The first focuses on water runoff and infiltration. The second explores air quality through real-time environmental data. While both topics differ in scale and complexity, they share the same underlying goal: making environmental processes visible within the user's physical context.

The runoff scenario focuses on a process that is highly spatial but often difficult to imagine from data alone. Terrain models, infiltration values, and hydrological datasets contain detailed information, yet interpreting them requires expert knowledge. At the same time, runoff directly influences how water moves through landscapes and how environmental risks develop. Through simulation, water movement becomes visible. Users can observe where water accumulates, how it travels across a terrain, and how infiltration changes the outcome. Rather than presenting information as isolated measurements, the prototype focuses on relationships and cause and effect.

The simulation is based on an existing particle-based fluid system developed by an independent creator and adapted for use in MR. The system was extended with runoff and infiltration logic and optimized to run on the Meta Quest headset. While simplified, it provided a foundation for exploring how hydrological information could be communicated spatially rather than through conventional visualization methods.

The air quality scenario approaches a different challenge. Unlike water movement, air pollution is highly invisible. Most people encounter it through weather applications, or air quality indices. While these representations are useful, they provide little sense of how air quality differs between locations or changes over time.

To address this, the prototype translates real-time environmental measurements retrieved through an API into a spatial particle simulation. Pollutant concentrations influence the density of visible particles, while color differences distinguish between pollutant categories. The implementation builds upon the same particle system used for the runoff simulation but adapts its behavior to create a floating and continuously changing representation of air quality.

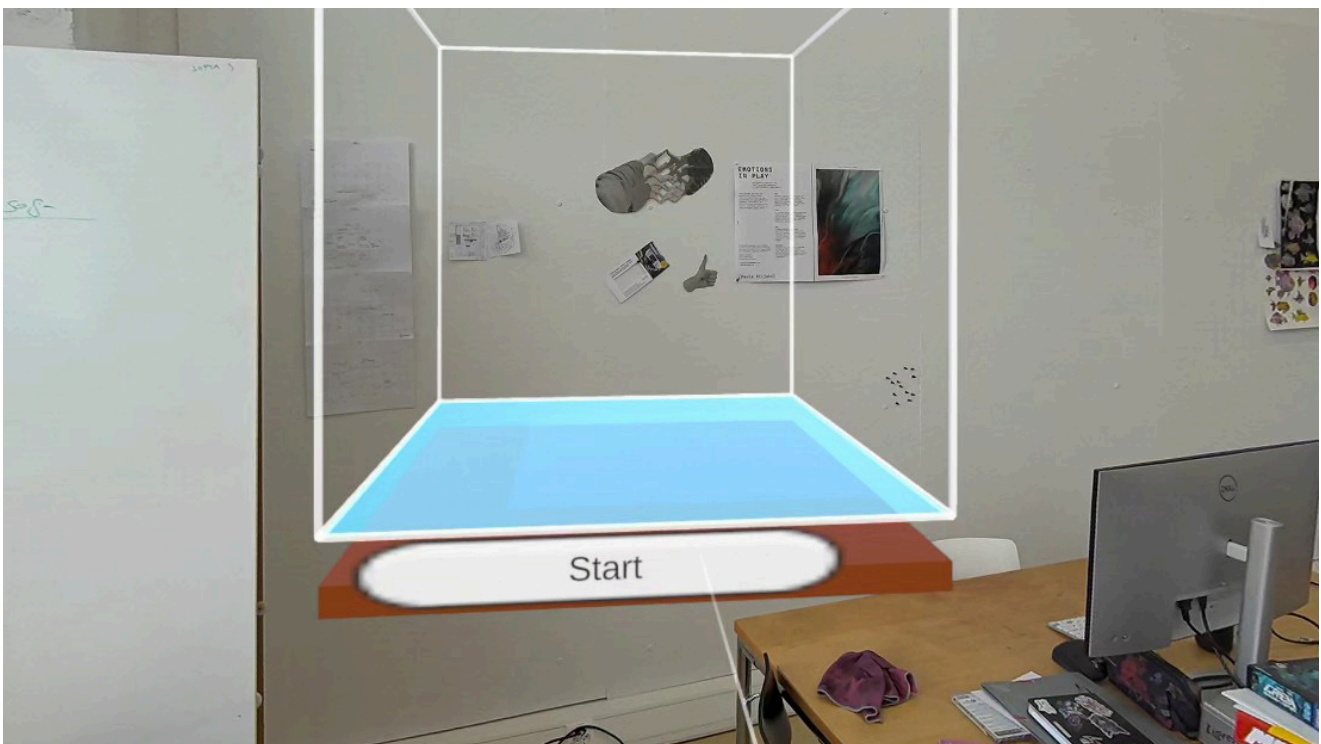
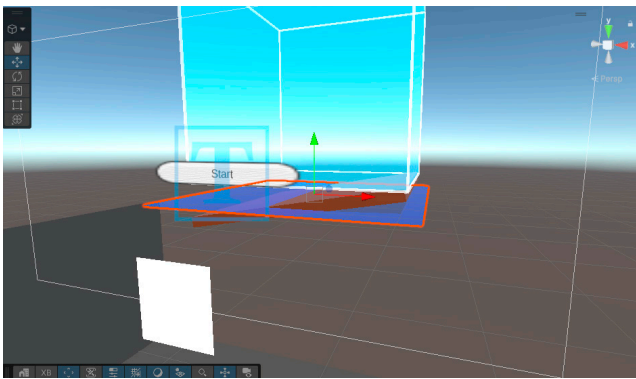
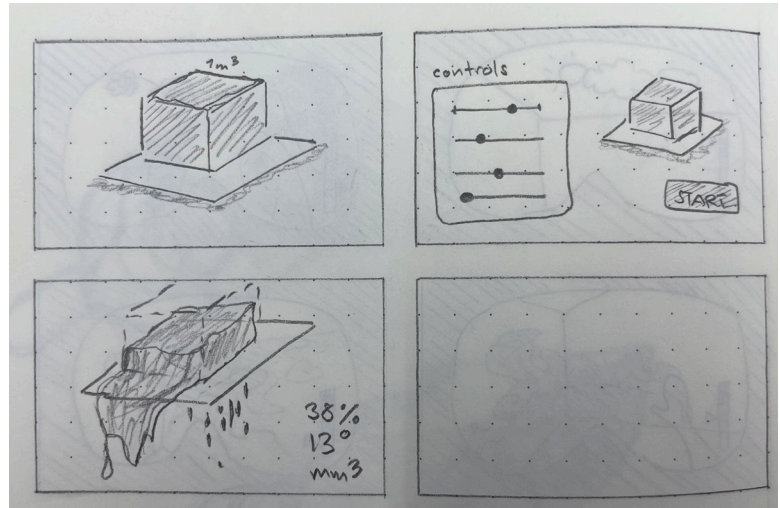
Several iterations focused on readability and comparability. Early versions varied particle size, transparency, and density simultaneously. Although visually interesting, this made comparisons between locations difficult. Later versions reduced the number of changing visual variables and relied primarily on particle density to communicate differences in air quality. This created a clearer relationship between the underlying data and its visual representation.

The use of real-time data also points towards future applications beyond the scope of this thesis. The successful integration of live environmental information suggests that similar approaches could be applied to a wider range of environmental datasets and monitoring systems.

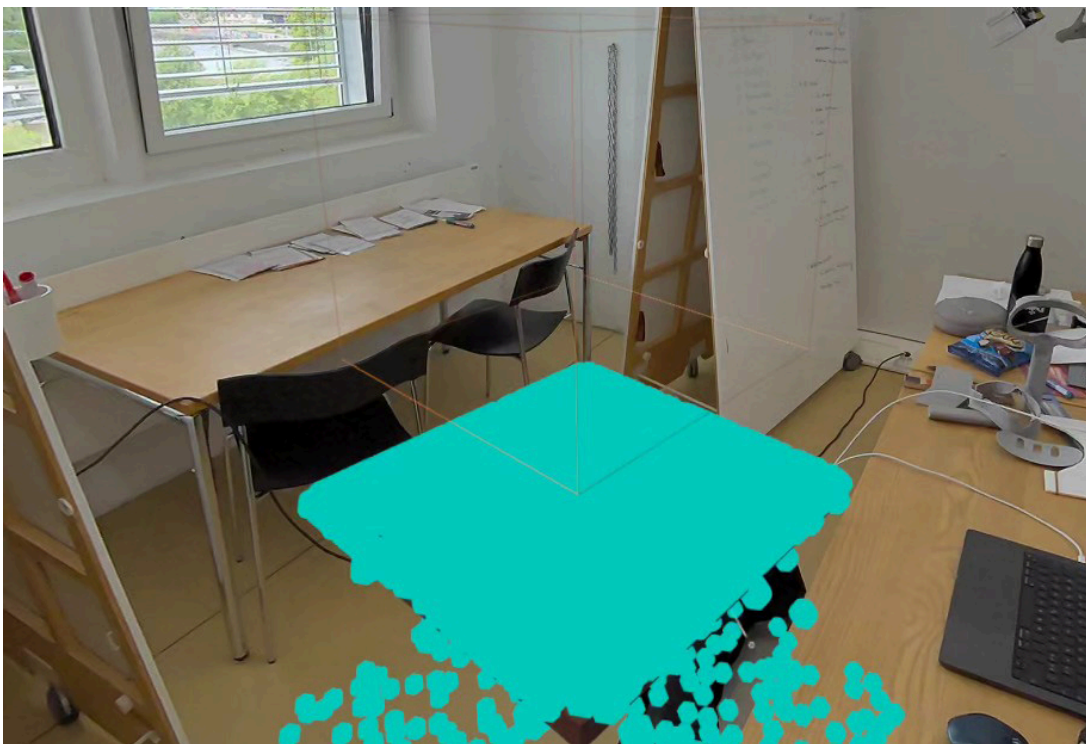
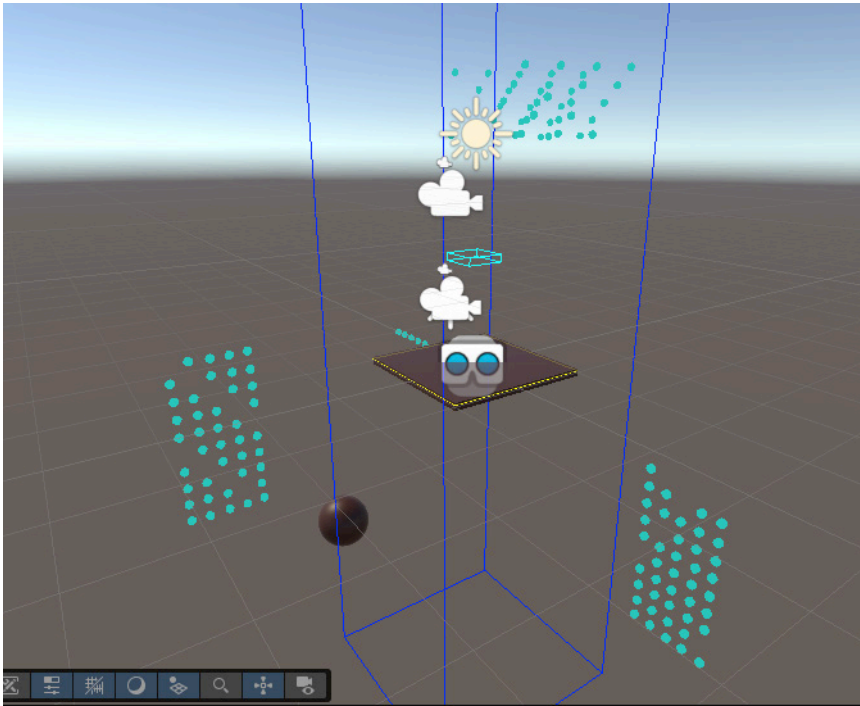
Both scenarios function as communicative representations rather than scientifically accurate simulations. Their purpose is not to replicate environmental phenomena perfectly, but to make them more tangible and easier to discuss. The focus is on understanding rather than precision or visual realism.

Accessibility became increasingly important throughout development. Earlier projects often prioritized exploration and experimentation. In the final prototype, accessibility became a primary design consideration. Interaction controls were simplified, visual complexity was reduced where possible, and additional contextual information was integrated through optional information panels.

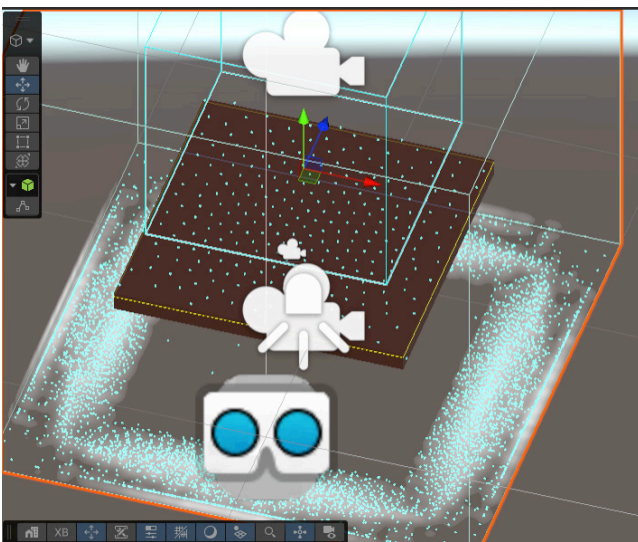
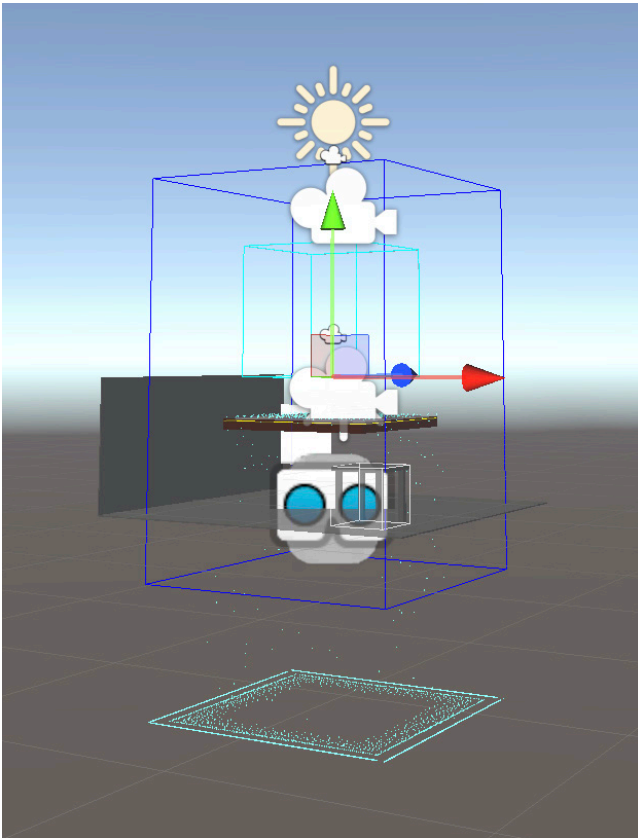
The outcome should be understood as a proof of concept rather than a finished product. It demonstrates one possible approach to communicating environmental information through MR. It reflects a shift that occurred throughout the project. Understanding often depends less on interaction itself and more on how information is contextualized and communicated. The final prototype became an exploration of that idea.

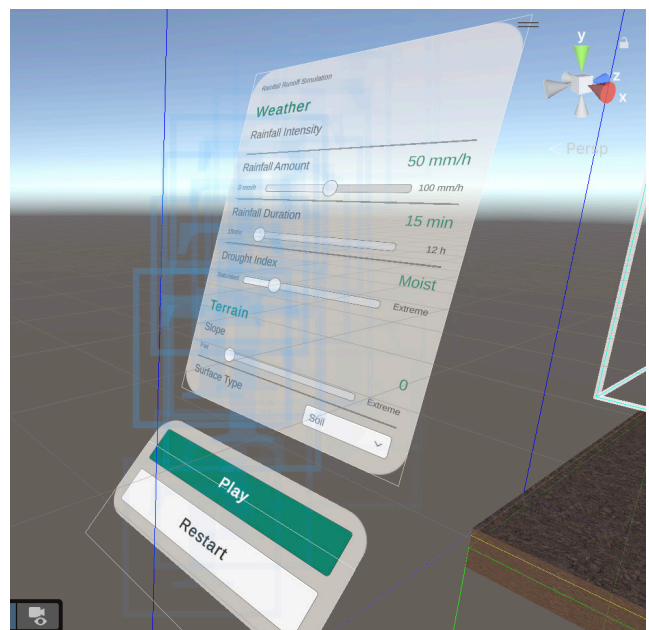
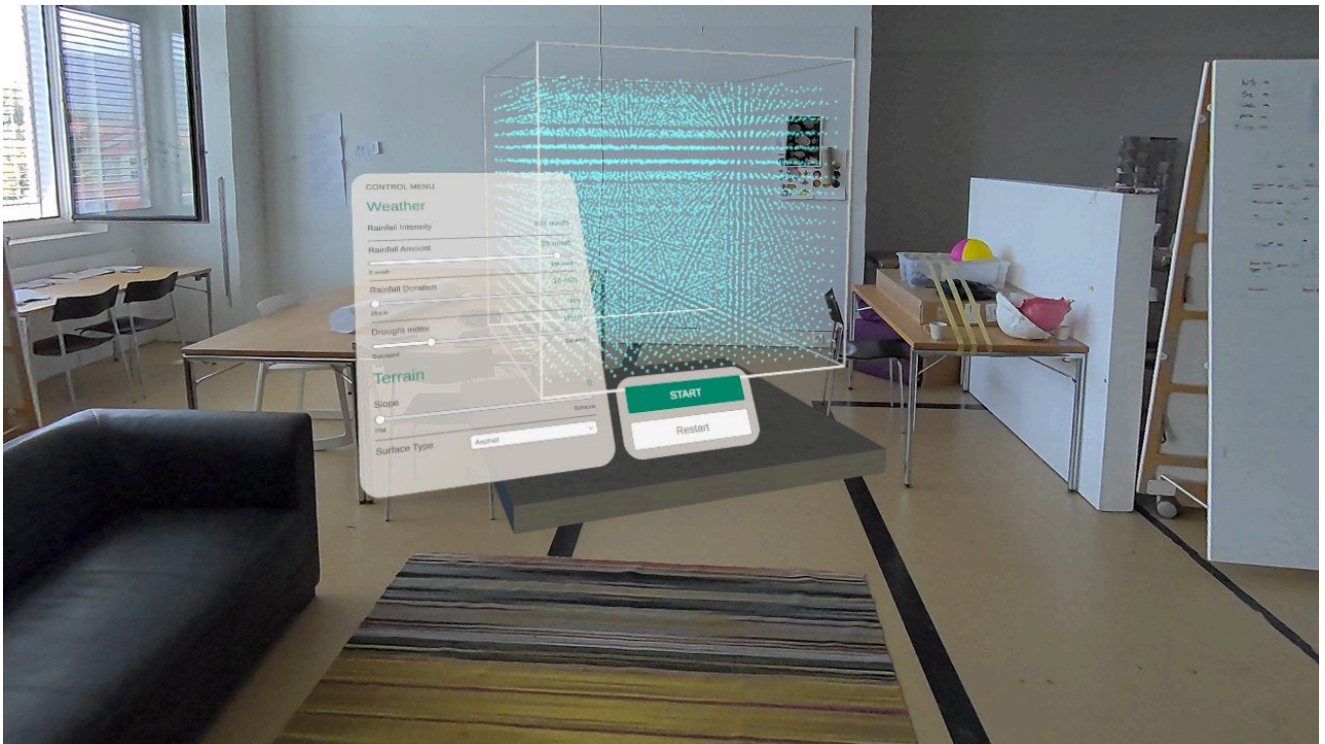
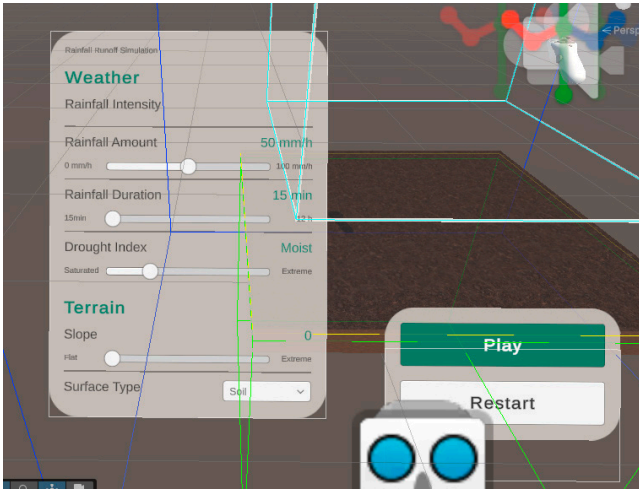


Storyboard and early prototype of run off simulation.

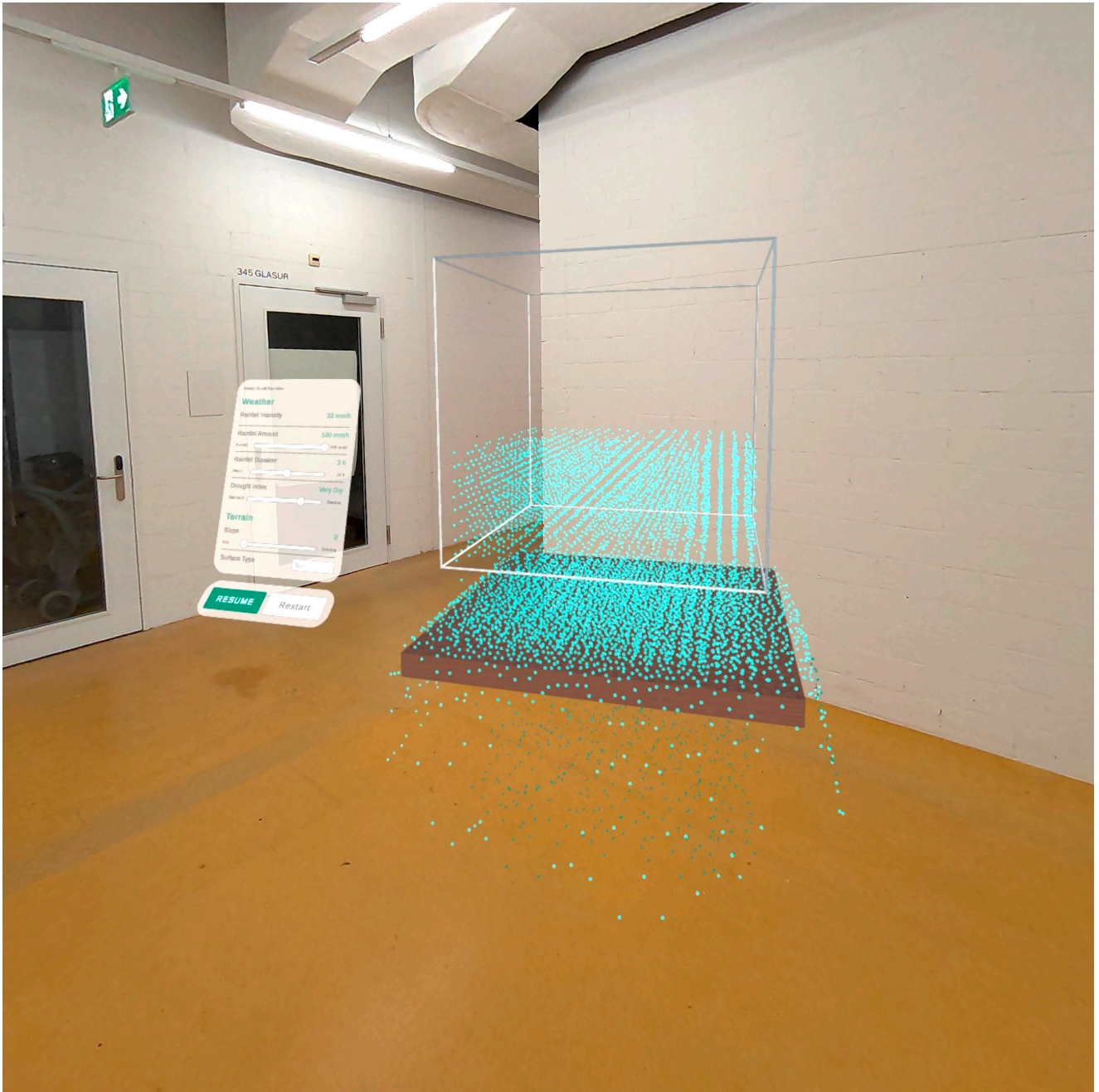


Early prototype showing an early version of the particle system.

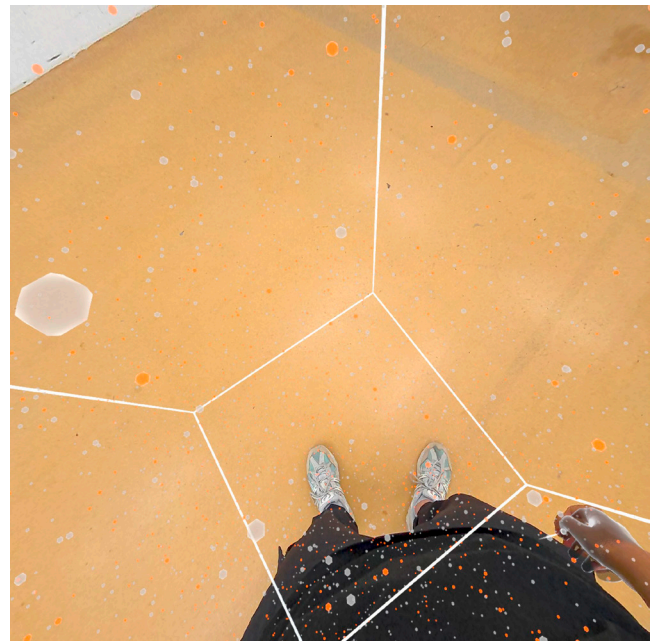
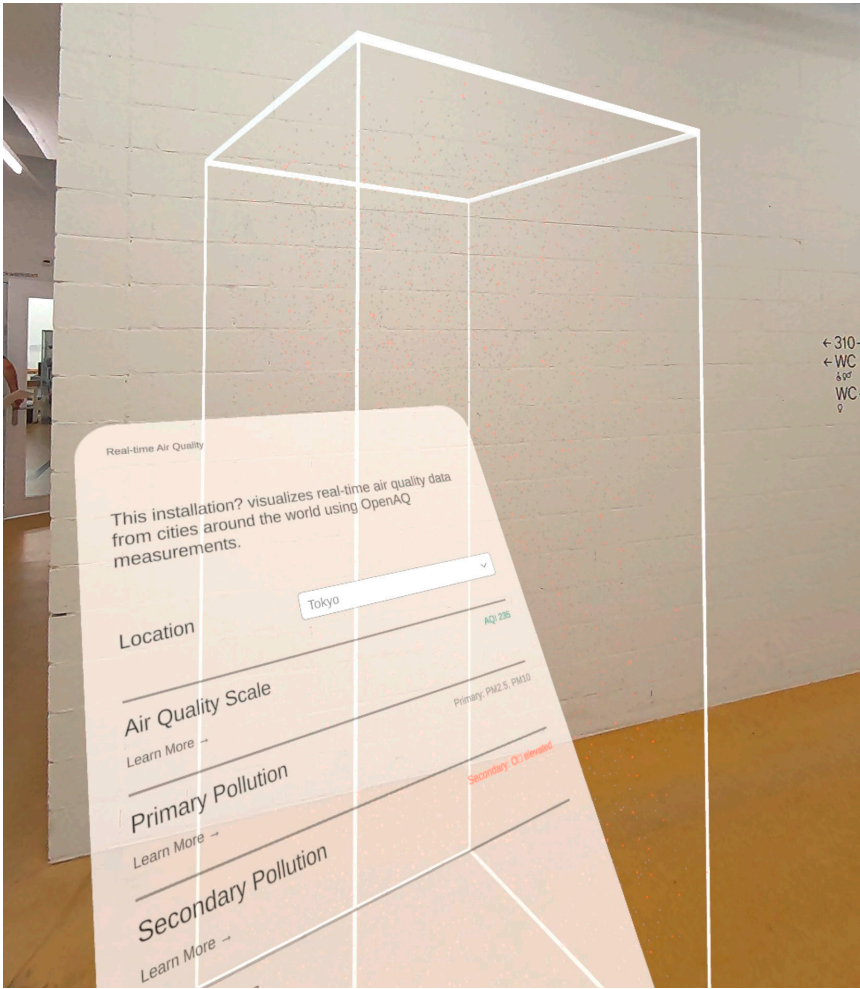




Implementation of UI and different iterations.



Final scene: run off and infiltration simulation.



Final scene: Real-time air quality visualization.



Final VR-stick for exhibition. Inspired by panoramic binoculars.

#### 10.4. Limitations and Future Work

Several limitations influenced the outcome of this project.

One of the most significant was the technical limitation of the hardware and development environment. The final prototype was developed for Meta Quest 3 headset. Even though this is one of the flagship models in the industry it has limited processing power. Relatively small changes to visual effects, such as increasing transparency of the particles, could lead to performance issues and application crashes.

These limitations influenced many design decisions. Visualizations often had to balance readability, performance, and visual fidelity. More realistic simulations were considered during development but were not always feasible within the available hardware constraints.

At the same time, this project represents my first larger development project. Throughout the process, technical decisions were shaped not only by hardware limitations but also by my own experience and the available timeframe. Certain concepts remained at the storyboard stage because their implementation would have exceeded my capabilities and therefore the project's scope.

One example is the representation of water. While the final runoff simulation successfully communicates water movement and infiltration, a more visually realistic representation would have required significantly more technical optimization to run smoothly on the headset. Similar compromises occurred throughout the project.

These constraints shaped the final prototype, but they also helped define its focus. Rather than pursuing technical realism, the project increasingly concentrated on communication and understanding. The final outcome should therefore be understood within the technical and practical limitations under which it was developed.

# 11. REFLECTING ON SPATIALLY INTUITIVE COMMUNICATION

The development of the prototypes provided an opportunity to reflect on the concept of Spatially Intuitive Communication beyond its theoretical definition. While the thesis defines the concept through four core characteristics — spatial grounding, intuitive engagement, contextual relevance, and embodied interaction — the prototyping process revealed additional nuances and raised new questions about the concept's application.

One of the strongest findings was the importance of recontextualization. The thesis argues that environmental processes often lose their spatial meaning when they are translated into conventional two-dimensional representations such as datasets and maps. Through the runoff and air quality prototypes, this became particularly apparent. What seemed difficult to understand in abstract form became more accessible once information was reconnected to a spatial visualization. The prototypes suggested that much of their communicative value came from reconnecting environmental information to a meaningful spatial context.

A second insight concerns the role of simulation. While the original definition emphasizes spatial understanding and embodied engagement, the prototypes demonstrated that dynamic simulation may be equally important. Rather than presenting static information, both final prototypes communicate through animation of processes. Users can observe relationships, cause and effect, and the movement of environmental phenomena. This suggests that simulation could be considered a complementary characteristic of Spatially Intuitive Communication, as it allows environmental processes to become visible rather than simply represented.

The prototyping phase also expanded the scope of the concept. Although the thesis develops Spatially Intuitive Communication primarily within the context of natural hazards, the air quality prototype demonstrated that the same principles may be relevant for broader environmental communication. This indicates that the concept may have applications beyond risk communication whenever complex spatial data must be connected to everyday experience.

At the same time, prototyping highlighted a limitation of the current research scope. The thesis proposes that spatially grounded experiences may contribute to shared understanding and common vocabularies. However, the prototypes were developed and evaluated primarily as individual experiences. Whether Spatially Intuitive Communication can support collective sense-making and shared responsibility remains an open question that would require further research and user testing.

## 12. REFLECTING ON THE DESIGN GUIDELINES

The design guidelines presented in Part 1 Chapter 8 were developed before most of the practical work documented in this thesis. They emerged from literature, case studies, and the new concept of Spatially Intuitive Communication. The prototypes provided an opportunity to test these ideas through practice and reflect on their relevance within a design process.

The guidelines were an important reference throughout the practical work. Rather than following them as fixed rules, they helped frame decisions during the design process and provided a way to reflect on different concepts and prototypes.

The practical work did not challenge the overall direction of the guidelines. Instead, it revealed which aspects became particularly important during implementation, which required a more nuanced perspective, and which remain assumptions that require further validation.

### 12.1. Spatial Grounding

Of all categories, Spatial Grounding remained the most convincing throughout the project.

The individual guidelines feel less like separate considerations and more like different expressions of a common principle. Whether through precise anchoring, human-scale comparisons, or navigation across scales, the underlying goal remains the same. Environmental information becomes easier to understand when it remains connected to familiar reference points.

This category also formed the foundation for many of the ideas.

### 12.2. Intuitive Engagement

Designing for recognition, supporting exploration, considering hardware limitations, and providing information through different modalities all contribute to accessibility and understanding. At the same time, they address very different aspects of the user experience, which makes this category feel broader than its title suggests.

Looking back, what connects these guidelines is not necessarily engagement itself, but the reduction of barriers between users and information. Throughout the project, accessibility became increasingly important. Environmental data often requires prior knowledge and can quickly become overwhelming when presented without context.

The practical work reinforced the value of familiar patterns, clear visual hierarchies, and gradual information delivery. My understanding of intuitiveness therefore shifted away from interaction alone and towards reducing cognitive effort. In many situations, the most intuitive solution was not a new interaction, but a familiar one.

### 12.3. Contextual Relevance

The guidelines within this category address uncertainty, scenario exploration, and context-aware information delivery. Together they move beyond repre-

sentation and begin to address decision-making and preparedness.

While these ideas remain compelling, they are also difficult to evaluate through my design prototype alone. Many of the intended outcomes depend on long-term use and real-world application. Questions around uncertainty communication, local decision-making, and personal relevance require further investigation beyond the scope of this project. Despite this, the category still feels important and relevant for future work in this realm.

#### **12.4. Embodied Interaction**

This category prompted the strongest reconsideration of its original framing. Looking at the guidelines today, I find that they are less concerned with interaction mechanics than their title suggests. Comfortable session management, constructive risk responses, and collaborative spatial experiences all focus on what users do with an experience rather than how they control it.

This raises the question of whether Embodied Interaction is the most appropriate name. The category appears to describe a broader relationship between people, information, and decision-making. While embodiment remains important, it may not be the defining characteristic of the category.

The practical work also highlighted a distinction between engagement and communication. Many of the early interaction experiments generated curiosity and encouraged exploration. They were valuable as a design research tool and helped uncover alternative ways of engaging with spatial information. However, curiosity alone did not necessarily lead to clearer communication.

As the project developed, the focus gradually shifted towards participation, accessibility, and understanding rather than interaction for its own sake. The guidelines themselves still feel relevant, but this is the category I would revisit most critically if the guidelines were developed further.

#### **12.5. Cross-Cutting**

The Cross-Cutting category became increasingly relevant in my prototypes. Unlike the other categories, these guidelines are not tied to a specific aspect of MR. Instead, they address broader considerations that influence the entire design process.

Progressive disclosure, transparency, stakeholder integration, and graceful degradation all operate across multiple levels of a system. They influence how information is structured, how limitations are communicated, and how different audiences engage with a project.

This category feels less tied to MR and more connected to responsible information design. Many of these considerations would remain relevant regardless of platform or technology.

Some guidelines remain difficult to assess. One example is the idea of creating shared understanding between experts and non-experts. This was one of the motivations behind the project and continues to be an interesting direction. However,

the final prototype was never tested in a real participatory setting. As a result, I cannot say whether it actually supports communication between different stakeholder groups. At this stage, it remains an assumption that would require further investigation.

The same applies to transparency and trust. The project incorporates design decisions intended to support both, but evaluating their effectiveness would require user studies and longer-term observation.

### **12.6. Technical Implementation Notes**

The Technical Implementation Notes originally functioned as supporting considerations accompanying the guidelines. But they deserve greater attention than I initially gave them.

Spatial accuracy, hardware limitations, multi-user synchronization, and computing power are often discussed as technical challenges. During development, however, it became clear that they directly influence design decisions. Technical limitations shape how data can be visualized, and which interactions remain feasible.

Rather than existing as a foot note, these considerations influence all categories simultaneously. In this sense, they are not merely implementation concerns but active design constraints.

Future versions of the guidelines could make this relationship more explicit. Technical realities do not simply affect execution. They influence the communication possibilities of the medium itself.

### **12.7. Closing Reflection**

Overall, the prototyping process did not fundamentally change the guidelines. It helped clarify which guidelines became most relevant in practice and where further refinement may be needed. Spatial Grounding remained the strongest category, while Embodied Interaction raised the most questions regarding its current framing. Several aspects of the guidelines, particularly those related to shared understanding and stakeholder participation, remain areas for future research.

## 13. OUTLOOK

Throughout this thesis, Spatially Intuitive Communication was explored through the lens of natural hazards and environmental data. While these topics provided a clear context for the research, the practical work suggests that the concept may be applicable beyond its original scope.

Many of the challenges discussed in this thesis are not unique to risk communication. For example environmental monitoring, climate adaptation, urban development, mobility systems, and energy infrastructure all rely on spatial information that can be difficult to communicate to non-experts. As datasets become increasingly complex, there is growing value in approaches that help people relate information to places and environments they already understand.

One area that deserves further exploration is simulation. The final prototypes demonstrated how environmental processes can become more accessible when they are experienced over time rather than presented as static information. Future work could investigate how simulation supports understanding of long-term and often invisible processes such as groundwater dynamics, urban heat islands, ecosystem change, or climate adaptation measures.

Another opportunity lies in collaborative experiences. One of the motivations behind this thesis was the idea of creating shared understanding between experts and non-experts. The current prototype was developed as an individual experience, but future iterations could explore how multiple stakeholders engage with the same spatial information simultaneously. Municipal planning processes, public consultations, and community workshops could provide valuable contexts for investigating this potential.

The concept of Spatially Intuitive Communication may also become less dependent on a specific technology. What matters is not necessarily the headset itself, but the ability to reconnect information with the spatial context it describes. Future applications could take many forms, from MR experiences to public installations or exhibitions.

The runoff and air quality prototypes represent only two possible applications. Rather than providing a finished solution, they open a design space that remains largely unexplored. As environmental information becomes increasingly relevant to everyday life, finding new ways to communicate complex spatial processes will become equally important.

Whether through MR or other forms of spatial communication, the opportunity to make environmental information more tangible for layman remains worth exploring.

## **ACKNOWLEDGMENTS**

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Thanks to my fellow students and friends for their inputs and patience during the process.

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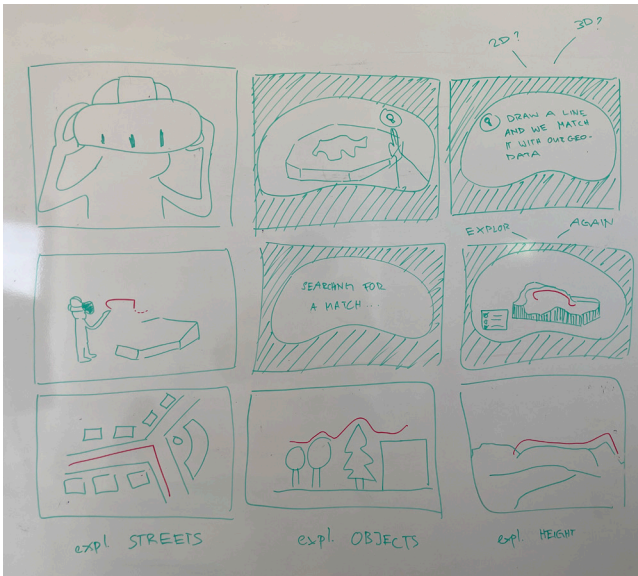
## Part 2

All the images in the Documentation are the Author's own images

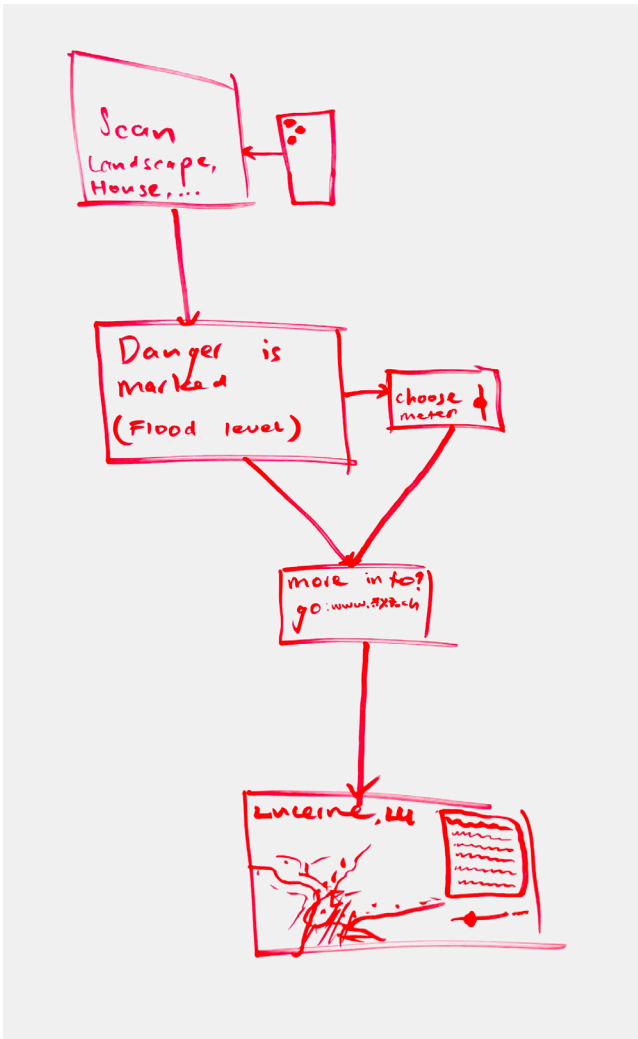


# APPENDIX

## ADDITION TO SWISSTOPO PROTOTYPE



ADDITION TO LOW-FIDELITY FLOOD SIMULATION


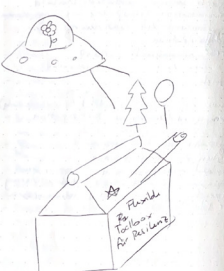


**PERSONAL NOTES: PLANAT-ZUKUNFTSFORUM 2025  
"RISIKOKULTUR GEMEINSAM GESTALTEN"**

**PLANAT ZUKUNFTSFORUM 2025**

- Standortbestimmung
  - Michèle Mink ← Risiken kommunizieren
  - Glaube Risikokultur
  - Wandel ~~ist~~ integrieren Risikokultur
  - Sind wir risiko-basiert umherwandern?
  - 88% Verwillingung: Zeitkonflikte (Schwierigkeit)
    - ↳ Wandel mit den Leuten, steht für Leute
  - Wie motiviert man Leute etwas zu tun?
    - ↳ Man muss (besten) leben etwas zu tun können
  - „Gemeinsame Lessons“
  - Wie ist der Prozessdialog → IRM
  - Wie sieht unsere Gesellschaft aus?
    - ↳ z.B. Altkern, Mythen (vulnerable team)
  - Langsame Projekte / Slow Science steht
  - Caregiving Communities
  - Mobilisierungskraft → Social media
  - Es fällt gemeinsam Wahrnehmung; zu große Verletzlichkeit, steht Vorbereitung
  - Utopie: würde Leute heute von unannehmer Präzision ohne Flut
  - Solidarität
  - „Märchen der Betroffenheit“
    - ↳ Behaupten gestalten sich nicht anders als Betroffene der Erdbeben Atlas
    - Akzeptanz (für Abstimmung)
    - April im 2024 → Prozess haben werden
    - ↳ Entscheidungen, Reaktionen

- Gespräch **HÜRDEN & ANSAATZ** 100 Jahre sind zu jung
  - kontinuierliche Veränderung der Risiken (große Unsicherheit)
  - Prozesse zu langsam → immer hinterher
  - 7 Problem Lücken vs. Ursache z.B. Klimawandel
  - viel zu abstrakt zum Kommunizieren, nicht genug Veränderung
  - Ist nicht „Risikokultur“?
  - Dimensionierungsprozess
  - „Mir ist noch nie was passiert“
    - ↳ Aber Morgen hat die Bedeutung
    - ↳ Akzeptanz Risiko → Teil der Kultur
  - Abstrakt fördert Konsequenzen
  - Ungleichheit von Risiken über Zeit
  - Kommunikation der Unsicherheit auch über lange Zeitperioden
    - ↳ Faktor Mensch
    - ↳ Sensibilisierung der Bevölkerung
    - ↳ Lernphase & Vorbereitung Bevölkerung
  - Rolle der Medien →
    - ↳ Mangel an Ressourcen für Eigenverantwortung
    - ↳ Angst vor Veränderung / Anpassung
    - ↳ Katastrophenwissen
    - ↳ Risikowahrnehmung / Risikobewusstsein
    - ↳ Positive Botschaft für Zukunft
- **TALK-REGELIENZ FORDERN**
  - Zukunft ist abstrakt
  - Podcast: Moment der Wahrheit
  - Zeitschrift Society 2030 - Projekt Bala
  - Gemeinsames Bild der Zukunft nicht
  - Zukunftsbild: Empathie, Offenheit, Empowerment, Landschaft
  - Von dem Besonderen, Landschaft studieren und Mänschen zu erkennen
  - Systemisches Denken
  - „Fehlendes mündigkeitskultur“ → Transformation, Konstruktive Konstruktoren
  - Klare Ziele, konkret gestrichelt Umfeld
  - Kommunikation, Transparenz → Change Kommunikation
  - Trainingsmodule für Storytelling
  - Interdisziplinäre
  - Interesse an Zukunft wecken?
- Gespräch
  - Serie als „Polenhausinstitut“ (Wahrnehmung)
  - Umgang mit Mensch → Partizipation
  - „Tippereit künstlich erzeugen?“
  - Menschen zum Glück zwingen?
  - „Gemeinsames Zielbild“ → Teils Individualisierung?
  - Naturerfahrung kann man nicht ohne Lesen
  - Wie bekommt Dankbarkeit

- Zukunftsbilder «Risikokultur 2035»
- 
- Feldbeziehung wird nicht ersetzt
- Gespräch im (Erde)
- Handlungsfelder - Diskussion
  - Blick in Zukunft; Vorausschauen
  - Verantwortung
  - braucht dynamische Verantwortung?
  - permanente Wahrung Zuständigkeit
  - Prävention → Bewältigung
  - Risikokommunikation
    - ko-kreation
  - Solidarität
  - Bildung Awareness Rising
  - Wissensbrennstoff (alte) (Geld)
  - z.B. Japan - Naturerfahrung
  - KI & Datengrundlage → bessere Vorhersagen?
  - Fokus auf die Notwendigkeit
  - Mut zur Laune
  - Big Picture
  - Soziale Perspektiven
  - Jetzt Gefahrenbewusstsein → soll zu Risikobewusstsein gehen
- 

- Warum Material erhöht man sich von besseren Monitoring / Vorhersagen?
- Situation eigentlich gut dargestellt ...
- Warum ist Sozialisierung → Bewältigung
- Naturerfahrung dadurch anders
- da
- Handeln & Lernen
- Brauen Blick auf Risiko → Risikobildung
- Niveau helfen & prägen
- Was der passieren? → Anteil Dialog
- „Bringt mehr als, was darf nicht passieren“
- Weltbildgespräche: Chancen & © Zukunftsbilder
- Utopien bauen / erdelt & zeigen
- Wie macht man ein Zukunftsbild erlebbar?
- Gute Dinge brauchen Zeit
- Anything is Possible
- Wie können wir auf ein Ziel mit einigen?
- Unklarheit vs. Freiheit
- Unklarheit wird uns immer drückt
- Warum besorgen, aber wir müssen einen anderen Umgang, multiplizieren
- „No Risk No Fun“
- „Knowing the Risks Having the Fun“
- Eigenverantwortung
- Kommunikation
- Risiko = Chance (für Neu)
- In Götter es Vorhersagen?
- Narrative sind auch Bilder
- „Sinnlos vor...“ vs „Leben mit Natur“
- Risikoakzeptanz
- Kann man Risiko-Matrix befrichte umgehen
- positiv konische Begriffe/Erlebnisse
- z.B. Schwamm steht
- → hier bewerteten Plan Wasser
- → bessere Wahrnehmung, bewusste
- bewerteten der Naturerfahrung
- Aus einer inklusiven Haltung rein zu einer aktiven Haltung

- Die Natur darf sich verändern
- Flexibilität
- WAS WILL ICH FÜR TRIGGERPUNKTE SETZEN?**
- Mittelwörterdiskussion: Klimawandel, neue Risiken
  - Was sind Klimawandelsszenarien
  - Resilienz bezieht Veränderung
  - Umgang mit Unsicherheit
  - Vorausschauen - Bewusstsein
  - Chancen + Risiko - Management
  - Was ist die Gefahr? Wollen wir das?
  - Was sind unsere Future Scenarios
  - Zukunftsrelevante Elemente
  - Übungen
  - Stadtbezirke Kommunikation, fördern Resilienz?
  - Erwartungsmanagement
  - Umgang mit Unsicherheit: Lessons learned
    - ↳ Schritte
    - ↳ Medien
    - ↳ dokumentieren + Umsetzung
  - Leck beheben
  - Zielgruppen geteilt, Emotional wirksam
  - Brück Risikoverständnis
- Altkerngruppe: Kommunikation; Lösungsseite
- Nicht einfach um einen Bedarf zu gehen!
- z.B. Open Lab - Formate

- Altkerngruppe: Kommunikation; Lösungsseite
- Nicht einfach um einen Bedarf zu gehen!
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