

ISE

IMMERSIVE SPATIAL EXPERIENCE

The development of a novel assistive technology for dynamic spatial environment perception for the visually impaired

Master's Thesis by Juerd Mispelblom Beijer







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PREFACE

This report presents my graduation project, which stands as the most ambitious and extensive endeavor of my academic career. I have enjoyed the journey, which was filled with newfound skills, interests, and experiences

My heartfelt gratitude goes out to everyone who supported me. Their pivotal contributions have played a significant role in the project's success. Special appreciation goes to Christiaan and Jesse from Royal Visio, Special thanks to Christiaan and Jesse from Royal Visio. Their dedication in helping me understand the design problem and organizing necessary resources has been invaluable. Their work in the visual impairment sector and the development of new technologies is truly inspirational. I would also like to thank my coaches, Wim and Marco, who I have got to know so well during this extensive and often intensive process. Their guidance has not only steered this project in the right direction but also significantly shaped my identity as a designer. I am also immensely thankful to my coaches, Wim and Marco. Their mentorship extended beyond professional advice, and they have been wonderful mentors on a personal level, providing invaluable advice when needed. I would like to thank Sita, who was always by my side, both in successes and in moments when things did not work out as planned. Her patience, love, and drive for bringing structure to my chaos have been my

guiding light through this journey. I appreciate the professional insights provided by Jolanda Kremer, Tim in 't Veld, and Mark Lanting who lent me their expertise which greatly enriched my work. The contributions of Henk, José, Nico, Rik, Robbert, Rob, Henriet, Marcel, and Simon, who participated in field research and experiments, were crucial. Their involvement brought invaluable perspectives to this project. Daniëlle Straub and Ton van Weerdenburg from the Oogvereniging deserve a special mention for connecting me with many of these participants. I'm thankful to Martin Klomp and George Vegelien for their help with the Robot Operating System, their advice on building the prototype, and their insights into the future of this technological direction. Lastly, I would like to thank Martin, Adrie, Joris from the Applied Labs, and the team from the Model Making and Machine Lab of the faculty of Industrial Design Engineering (IDE). Their advice, provision of crucial components for the prototype, and their endless patience in answering my questions were instrumental in bringing this project to fruition.

I hope you find reading this report as enriching as I found working on the project.

EXECUTIVE SUMMARY

This project develops a novel assistive technology for aiding in mobility of the Visually Impaired in collaboration with Royal Visio. This technology provides VIPs with a dynamic tactile map of their environment to improve spatial awareness. The aim is to improve overview, wayfinding and orientation, while also improving the overall mobility experience by boosting confidence and independence through comprehensive awareness of the environment.

The initial research phase seeked to understand the needs and challenges in mobility faced by VIPs, both from a functional point of view, focusing on wayfinding and orientation, and on a psychosocial level, focusing on emotional and experiential needs that derive from the process. It was found that the absence of the visual sense significantly limits VIPs' ability to overview and comprehend their surroundings, hindering their orientation and use of distant environmental reference for movement, resulting in the reliance on physical guidelines. Reduced awareness of potential hazards and complicated wayfinding often leads focus the functional aspects of mobility. They experience a vigilant, alert state of mind, focusing mainly on avoiding risks and not losing their way. This intense focus diminishes engagement with the broader environment and leads VIPs to stick to familiar areas. Such limitations impact their independence but also their connection with society.

The review of current assistive solutions reveals that they primarily concentrate on similar functional aspects of mobility, using interface technologies that fall short in significantly enhancing environmental awareness and reducing the perceived lack of environmental awareness.

This gap highlights the need for assistive technologies that focus not only on wayfinding and navigation but also on these experiential aspects. The project proposes a multidimensional, spatial interface technology akin to conventional tactile maps but of dynamic nature, is capable of real-time updates based on the actual environment, moves along with the user and subsequently is able to display non-static and small-scale environmental elements. This dynamic tactile map aims to provide a deeper sense of environmental awareness and understanding.

In the subsequent research-through-design phase, a prototype of the conceptual product, that provides a dynamic top-view map of the environment on an electronic braille screen, is put to the test. Despite highlighting the potential of this conceptual direction for spatial understanding, orientation and free, confident movement, the experiment reveals significant requirements for improvement of the interface and environmental mapping technologies.

The final design, "Immersive Spatial Awareness," features an improved interface with in the form of a haptic augmented reality system that enables a dynamic 360° 3D perception of the environment, primarily through touch, but supplemented with multisensory elements. While significant technological development and Human-Centred-Design is required to realise this visionary concept, the applied technologies are grounded in actual research and existing technologies that see rapid development, highlighting the realistic potential of the concept. The design is supplemented with a roadmap that details and presents the development process towards the successful application of this technology.

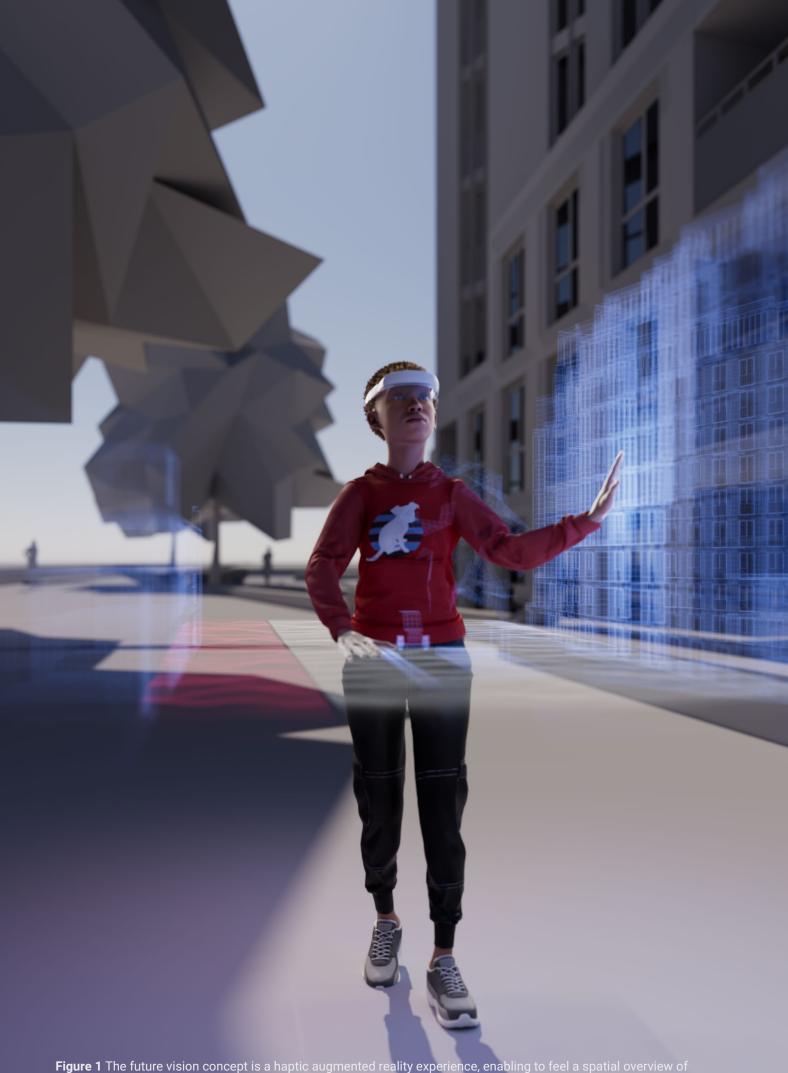


Figure 1 The future vision concept is a haptic augmented reality experience, enabling to feel a spatial overview of their surroundings

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READER'S GUIDE

The report consists of 3 phases. Each phase starts with an explanation and process visualisation, that explains the structure of that phase and in which chapters different activities can be found. At the start of each chapter, an explanation and overview of the chapter is provided.

Images and statements based on literature are accompanied by (references). Images and figures without citations are the student's own work.

"Quotes in the text are grey. Quotes by participants are adapted to improve their readability. The original quotes can be found in the accompanying appendix."

Elaborations

Elaboration sections substantiate or provide extra information about a specific topic.

GLOSSARY

Assistive Solutions: Technologies or strategies designed to aid individuals with disabilities, enhancing their ability to perform tasks that might otherwise be challenging or impossible.

Cognitive Map: A mental representation of one's physical environment, aiding in navigation and spatial awareness.

Dynamic Tactile Map (DTM): An concept introduced by Mispelblom Beijer in 2019, involving a dynamic, tactile representation of spatial environments, aiding visually impaired people in navigation.

Human-Robot Interaction (HRI) Lab: A research lab at TU Delft focusing on human-centered artificial intelligence, aiming to create AI that forms respectful, reciprocal partnerships with people.

Integrated Product Design (IPD): A multidisciplinary field combining design, technology, and research, focusing on innovative, sustainable, and ethical product development.

Object with Intent (OWI): The starting point for the interaction in the project, wherein an intelligent device behaves as a collaborative partner and acts based on its own intent.

Spatial Problem-Solving: The ability to navigate and make decisions about movement and location in space.

Ultra-Rapid-Prototyping: A quick and efficient method of creating early versions of a product to test and iterate design concepts.

Visually Impaired People (VIPs): Individuals who have a visual impairment that significantly affects their ability to see.

Wayfinding: The process of using spatial and environmental information to navigate to a destination.

Immersive Spatial Experience (ISE): The final design concept that provides a dynamic environmental perception through an augmented reality (AR) system.

1

INTRODUCTION

This project is dedicated to finding a new approach to assistive solutions for visually impaired individuals that enriches the environmental awareness and levitates mobility to a means to explore and engage with the world.

In pursuit of a project partner aligned with this innovative vision, the project engaged with Royal Visio, a leading center for expertise in supporting visually impaired and blind people.

The chapter begins by introducing the core design problem of the project. It then explores the project's vision and the strategy used to tackle this issue. The chapter details the applied methods and initial technological considerations that guided the development towards a solution.



Figure 1.1 The resulting design of the previous project

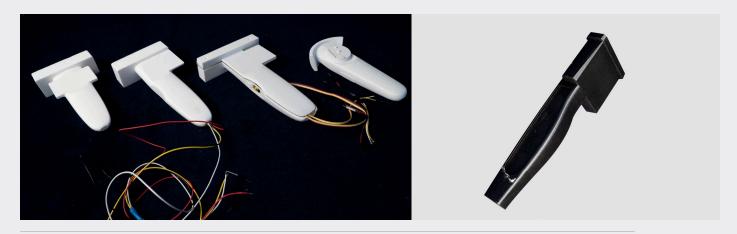


Figure 1.2 Prototypes from the previous project

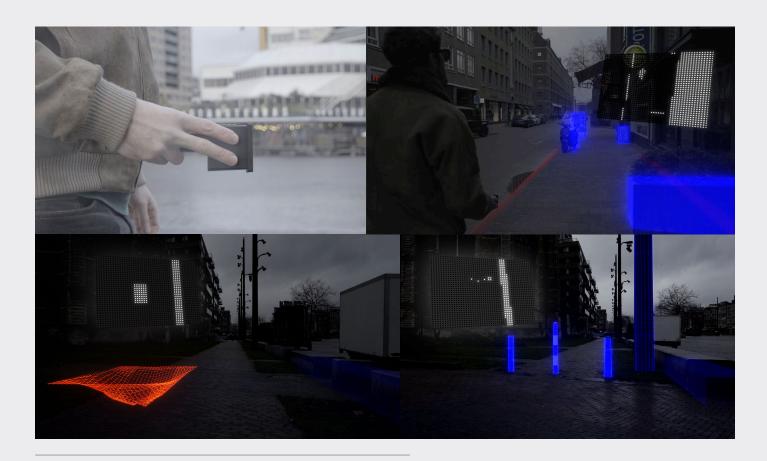


Figure 1.3 The video that presented the DTM concept in the previous project

1.1 PROJECT PARTNERS

This project involves several key partners:

ROYAL VISIO

As the client, Royal Visio is a prominent Dutch foundation dedicated to aiding those with visual disabilities. Two members of Visiolab, the department that tests and examines new developments for VIPs, closely participated throughout the project. They were involved in scoping and decisionmaking at important parts of the project. Their involvement in the project is multifaceted, including financial support, expertise sharing, and facilitating access to the target group, mobility trainers, and occupational therapists, which enabled me to immerse myself in the problem. In the end, Royal Visio gains intellectual property rights from the project.

DELFT UNIVERSITY OF TECHNOLOGY

This project is done as a graduation project at the faculty of Industrial Design Engineering (IDE) at the Delft University of Technology for the master's degrees Integrated Product Design (IPD) and Design for Interaction (Dfl).

HUMAN-ROBOT INTERACTION LAB

Part of TU Delft's IDE faculty, the HRI-lab specializes in human-centered AI. Their goal is to design AI that "establishes respectful, reciprocal, socially appropriate partnerships with people" over time (Expressive Intelligence Lab, 2022). Their role in the project involves applying the 'Object with Intent' principle in the design of assistive technology. Regular meetings with the HRI-lab have significantly influenced the project's direction and philosophy.

VI PARTICIPANTS

Central to the project's success is the involvement of 10 visually impaired individuals. Most of these people regularly take part in national research into VI accessibility and technology development and thus have experience participating in experiments. They participated in interviews, field research, explorative design-driven research and prototype experiments. Their insights are vital to the research, and for privacy reasons, they are referred to by fictional names.

1.2 PROBLEM STATEMENT

The population of visually impaired individuals is on the rise with over 2.2 billion people suffering from some form of a visual impairment, and over 300,000 visually impaired individuals in the Netherlands alone, and this number is steadily increasing (Oogfonds, 2022). One of the most significant challenges faced by visually impaired people (VIPs) in their daily lives is the inability to travel independently (Marston & Golledge, 2003). In many cases, the inability to travel independently leads to social isolation and affect their productivity, employment, leisure, and self-maintenance activities (Marston & Golledge, 2003; Walker & Lindsay, 2006). Therefore, the development of aids for visually impaired (VI) mobility is becoming increasingly relevant.

VIPs have many options for assistive solutions, the most important being the traditional mobility aids, the white canes and guide dogs. These are crucial for VIPs but have limitations. Canes offer limited obstacle protection (Farmer & Smith, 1997), while guide dogs, though significantly reducing mental strain affiliated to mobility for the VIP, demand significant commitment and are scarcely available (Chanana et al., 2017; Koninklijke Visio, 2021).

Recent decades have seen the introduction of advanced electronic aids like smart canes and Al-powered glasses (WeWalk, 2020; Orcam, 2023). Although they have made

significant improvements in mainly the VIPs ability to navigate the world, and some of these tools apply modern technology, they have not managed to replace the traditional aids as primary tools that can be used without depending on other tools (Chanana et al. 2017).

These tools approach a traditional approach that focuses on technology and functional benefits in wayfinding which, while useful, overlook the broader, personal and social aspects of mobility (Chanana et al. 2017, Seybold, 2005). This focus, along with the application of nonspecialized, conventional interface technology that falls short in addressing deeper human needs linked to mobility, such as feeling safe, confident, and engaged with the surrounding world.

This project addresses the shortcomings of existing assistive technologies for Visually Impaired (VI) mobility that fail to break free of the traditional tools. It applies a more holistic approach that focuses on integrating needs for safe, effective wayfinding with human needs, and advanced technology. The goal is achieving comprehensive spatial awareness that enables VIPs to navigate, understand, and explore their environment independently and confidently.

1.3 ASSIGNMENT & APPROACH

PROJECT VISION & GOAL

The goal of the project is to design a new concept for an assistive technology that improves environmental awareness for independent pedestrian mobility of VIPs and, consequently, quality of life. Mobility of VIPs presents a multifaceted design problem that demands a holistic approach.

To enable independence the project aims to create an assistive technology that fuses with the VIPs perceptive sense and enables them to perceive a comprehensive spatial overview of their environment. The design of the technology goes beyond addressing functional mobility needs aimed at effective and safe wayfinding but also aims to enrich the VIPs' experience and engagement with their environment, enabling a new mode of mobility and an improvement of the overall experience of the mobility process for VIPs.

This project proposes an empathetic approach (Sleeswijk Visser, 2009) to the design of assistive technology for the Visually Impaired that transcends the traditional functional focus by considering emotional, psychological and experiential aspects alongside the (still considered crucial) functional aspects when developing design solutions.

To develop this thorough understanding of the mobility of VIPs, deep personal immersion in the world of VIPs by the designer is required. This involves extensive conversations, participating in mobility training, and undergoing simulation sessions to enable a personal understanding of the VIPs' experience which is a cornerstone of this project's approach to developing a human-centered solution.

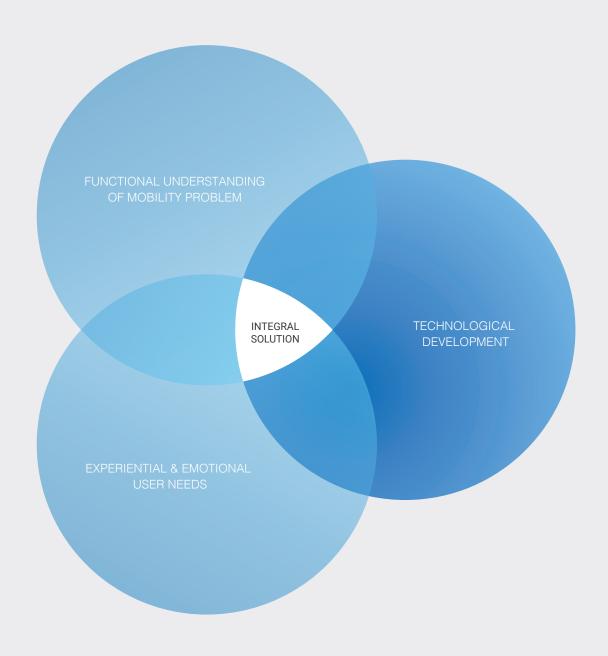


Figure 1.4 The design of assistive solutions should approach mobility from a holistic perspective

SOLUTION STARTING POINTS

This project, building on Mispelblom Beijer's 2019 work, further develops the concept of dynamic spatial environment perception for VIPs.

A spatial representation that reflects the actual, real-life environment delivers a far more comprehensive overview than traditional assistive technology is able to provide.

This is the central conceptual/technological starting point for the project. From here on, this concept will be called the **Dynamic Tactile Map** (**DTM**) and has the following characteristics:

- A spatial (i.e. either a 2D or 3D)
 representation that is displayed on
 some form of a (digital, updateable)
 multidimensional tactile interface (in this
 project, a digital braille screen).
- From the user's perspective, i.e. when the user moves and turns, the map moves and rotates along
- Realtime updating with the live environment, i.e. it contains non-permanent and dynamic environmental elements.

Next to this, the concept of an **Object with Intent** (*Rozendaal et al., 2019*) is taken as the starting point for the interaction. An Object with Intent is an intelligent device that behaves as a collaborative partner and can act based on its own intent. This concept is a field of expertise of the Expressive Intelligence Lab, one of the project's partners.

Together, these concepts will drive the design of the conceptual product.

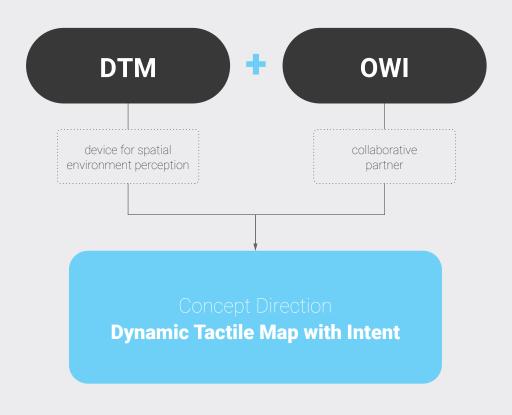


Figure 1.5 Solution Starting Points

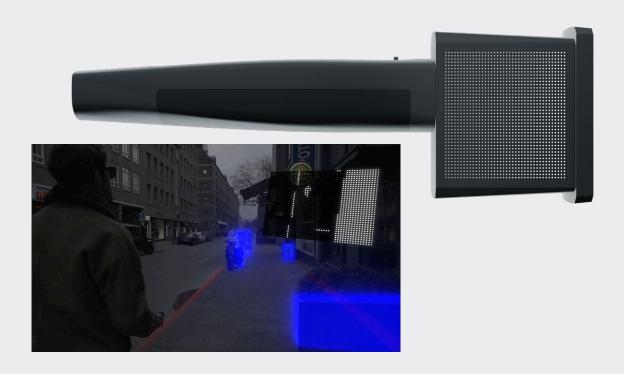


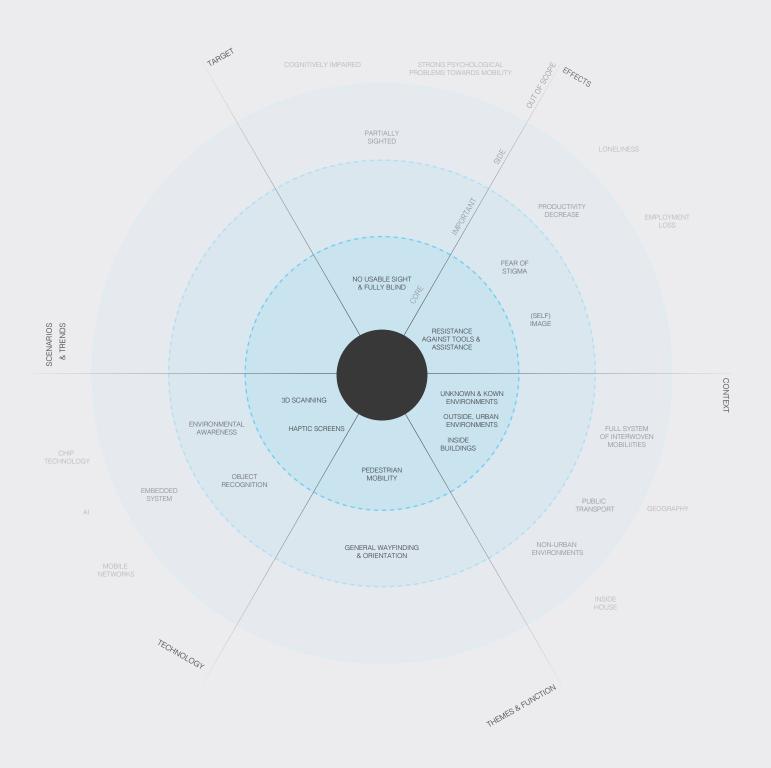
Figure 1.6 Impression of the Dynamic Tactile Map contcept (Mispelblom Beijer, 2019)

SCOPE

To ensure inclusivity for the full group of visually impaired individuals, the design of the product assumes no useful vision during mobility at all and in the design stage focuses those who are socially and fully blind. To reduce complexity, the project further focuses on a target group without multiple impairments, and who already possess basic mobility skills.

At the heart of this initiative is the development of an innovative assistive technology for pedestrian mobility. By concentrating on walking mobility, the project intentionally sets aside interactions with other travel modalities, such as train, bus or taxi, enabling a focus on the specific challenges and requirements of pedestrian mobility.

The ultimate goal is to create a conceptual product that is reliable and applicable in as many situations as possible. This means designing a solution that does not rely on any prior environmental preparation, which leads to the greatest independence.



DESIGN APPROACH

This project serves a double Master's degree in IPD (Integrated Product Design) and DFI (Design for Interaction). This project aims to blend knowledge from both fields into a cohesive project.

IPD "integrates design, technology, and research to enable students to develop new perspectives on product design. They learn to shape innovative, sustainable, and ethical products that benefit people, society, and the planet." (Delft University of Technology, 2023). In this project, the IPD approach is reflected through the integration of Human-Centered research that centralises the user and human aspects with the development of novel technology.

DFI "focuses on the relationships we create between people and their world through design - the new behaviours and experiences they enable." (Delft University of Technology, 2023). The project reflects the DFI approach by adopting an Empathetic design approach (Sleeswijk-Visser, 2009), characterized by deep personal immersion in the user's world and the design problem to form a truly usercentric design focus and the participatory development of technology.

Combining these directions leads to a Human Centered Design approach that prioritizes immersion in the user's experience and collaborates closely with end users in solution development. This includes integrating the creation of realistic, well-tested novel technology with human-centered research

methods and a exploratory approach. Methods range from quick-and-dirty techniques like Wizard-of-Oz style enactments and Ultra-Rapid-Prototyping, to more sophisticated prototyping of the electronic conceptual product.

DESIGN PROCESS

The project adopts a triple diamond structure, consisting of three key phases:

Analysis and Immersion Phase: This initial stage focuses on developing a deep understanding of the issues faced in mobility by VIPs. It involves analyzing the problem and immersing in the VIPs' experience through extensive contact with the target group to form a well-substantiated design focus.

Research-through-Design Phase: In this phase, the understanding of the design problem, along with value propositions and potential solutions, undergoes extensive experimentation to build empirical knowledge about the problem and solutions. The phase divides the work into two design directions: Object with Intent (OWI) and Dynamic Tactile Map (DTM), to build focused knowledge efficiently.

Synthesis & Design Phase: This phase integrates all the gathered knowledge into an innovative yet realistic design. A roadmap is developed to drive future development and to communicate the concept's feasibility.

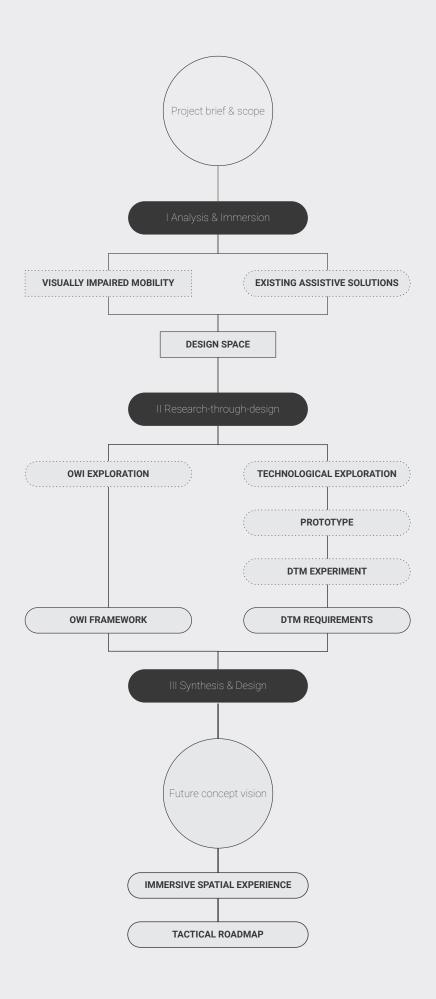


Figure 1.8 The design process

IMMERSION AND ANALYSIS

Navigating the world without sight presents unique challenges and demands innovative solutions. This chapter describes the initial phase of the project, and delves into the multifaceted nature of mobility for the visually impaired, exploring how they traverse the world and how their experiences differ from the sighted. It examines the existing paradigms, challenges, and the cognitive and emotional complexities of navigating a world with a vision impairment. Through a blend of critical analysis and immersive research,

a vision emerges for assistive technology that innovates on the traditional approach, offering new perspectives and possibilities in enhancing mobility for the visually impaired. In the overview of the chapter on the right, it can be seen how this initial phase is split up in two components, the research into user needs and the analysis of existing solutions, respectively chapter 3 and 4, to come a problem statement and a design goal and vision, that will serve as an input for the next phase.

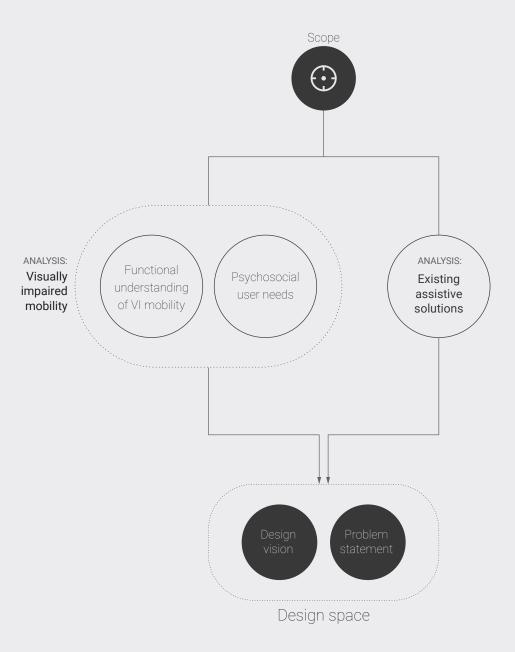


Figure I.1 Immersion and Analysis Phase Overview

2 MOBILITY FOR THE VISUALLY IMPAIRED

Mobility for the visually impaired is a complex, layered process that encompasses many different types of problems and factors. Current research into user needs in VIPs' mobility often adopts a traditional, medical approach, focusing on physical and cognitive limitations in mobility. However, spatial abilities are just a part of understanding VIPs' mobility. Researchers like Worth (2013), Seybold (2005), and Gleeson (1996) advocate for more emphasis on human factors, such

as psychosocial issues, which are crucial for effectively aiding VIPs.

By examining these layers of their mobility experience, from cognitive strategies to emotional responses and psychosocial factors, insights obtained that are crucial for the formation of a design focus for a novel assistive technology that is grounded in a truly human-centered approach.

2.1 DEFINITION AND SIGNIFICANCE OF MOBILITY

To understand how VIPs function as spatial actors, and why mobility is difficult for a VIP, first, a clear definition of mobility and an initial scope within the topic of mobility must be set.

Mobility, as defined by Royal Visio, is the act of "getting from point A to point B" (Royal Visio, 2022).

Independent mobility, the ability to orient and move around independently is widely considered to be a prerequisite for a high quality of life and is intrinsically linked to many different aspects of life, such as access to education, maintaining a household, interpersonal interactions and relationships, professional life and the realization of potential, etc. (Royal Visio, 2022).

A VIP has many options to travel from A to B, such as walking, travelling by bus, taxi, train, etc. These are called transportation modalities. Walking mobility is at the center of all these modalities: It is the primary way to access other transport and is the only fully independent modality (i.e. that does not depend on others or transportation services to enable a person to travel somewhere): "One walks to get to public transportation, for example, to walk to the cab, to get around the house, to be able to explore your surroundings" (Royal Visio, 2022). Designing a solution for easier, more worry-free walking mobility is therefore central to empower VIPs to become truly independent.

Interaction with other modalities is highly relevant, however would yield unrealistic complexity in the design problem. Therefore, this report focuses solely on walking mobility, using 'mobility' to mean walking mobility unless stated otherwise. Exploration of these interactions is a topic for future research.



Figure 2.1 Impression of visually impaired mobility

2.2 MOBILITY PROCESS

PERCEPTION WITHOUT SIGHT

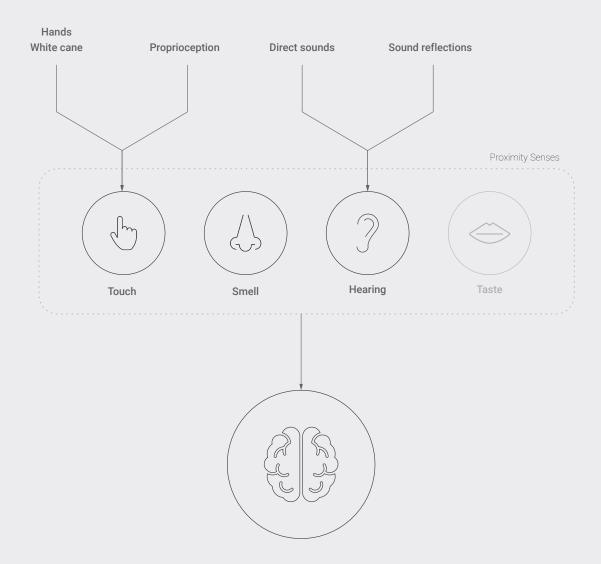
Understanding the way that VIPs navigate the world and experience mobility requires an understanding of the impact of **non-visual perception**.

Vision is key for reliable distance perception. It provides a rich and detailed view of one's environment that enables both a broad and a detailed understanding of one's surroundings, enabling the easy overview of a space, identifying places of interest and potential hazards, VIPs often miss out on this information (Banovic et al., 2013; Passini et al., 1986; Abd Hamid, 2013).

The absence of sight poses strong limitations of VIPs' ability to perceive their surroundings, which complicates their ability to travel through and interact with their environment: A positive experience of mobility and the ability to engage with the world is rooted in one's ability to perform complex tasks such as navigating traffic, avoiding hazards, and moving around obstacles. Such skills of safe and effective wayfinding, form the 'functional core' of mobility. For visually impaired individuals, the lack of sight makes these essential aspects of travel particularly challenging.

Without sight, VIPs rely on **proximity senses** like hearing, smell, and touch. The way in which these senses are used by people with a VI is illustrated in Figure 2.2 to the right. Hearing and smell provide environmental cues, but localizing their exact sources can be challenging. Touch becomes the most vital sense for understanding the immediate surroundings in a spatial manner (i.e. with awareness of spatial layout). This reliance on close-range perception significantly influences VIPs' interactions with their environment and their strategies for wayfinding and exploration.

The lack of an instant environmental overview for VIPs leads to a different experience of and interaction with environments and necessitates alternative strategies for navigation and exploration. These strategies rely on different types of sensory input. To comprehend the challenges VIPs face in wayfinding and mobility, this section examines three critical processes: cognitive mapping of environments, orientation, and moving through environments.



COGNITIVE MAPPING OF ENVIRONMENTS

ACTIVE EXPLORATION

A sighted person can quickly grasp a space's size, layout, contents, and atmosphere upon entering. They can see who's in the room, the furnishings, and how to reach their goal (Royal Visio, 2023). In contrast, for a VIP, an unfamiliar space can feel vast and abstract. As P1 describes:

"The space is something very abstract; it's just very big. Do you know what the universe is like all the way to the end? That's what this feels like. You also have no idea what's at the end of the road."

For VIPs, reflections of sound are crucial for understanding a space. However, this auditory information can be compromised by soundabsorbing materials like carpets and acoustic tiles, or overwhelmed by background noise, making spatial orientation challenging in such environments (*Passini et al.*, 1986).

P2 explains that large public spaces such as hospitals, city halls and public swimming pools are difficult because the acoustics are poor and there are large open spaces where there are no guide lines:

"You always unconsciously orient by your hearing, too. If that is disturbed, for example, by a garbage truck or truck making a lot of noise you start moving out of line, because you don't know where you are anymore."

To map an environment, VIPs engage in active exploration, meticulously memorizing various environmental elements and connecting them to create a comprehensive mental image, also called a 'cognitive map' or 'mental map' of the environment (Golledge et al., 2003; MacEachren, 1992). This mental map can later be used to plan routes and self-orientation based on recognizable environmental elements. The mental map contains all sorts of information and if you would ask a VIP about the cues they rely on for orientation and mobility, they would answer "everything". For example, tactile sensations like the gradient or tactile paving of a wheelchair ramp can indicate both an intersection and a step in one's path. Similarly, auditory signals, such as the distinct ping of an elevator marking each passing floor or the sounds at a pedestrian crossing, contribute to their spatial understanding (Williams et al, 2014).

Although VIPs are able to form a useful mental image through such exploration, creating and recalling these mental maps requires intense focus and memory, which can be challenging and not everyone is able to remember the spatial structure of places and routes they visit in their daily life (Golledge et al., 2003).

This mental mapping process requires lots of effort and it is often inaccurate. The lack of distance perception complicates understanding spatial relationships, making spaces and routes seem more complex and contain errors, due to inaccurate memorization of directions. As P1 notes, even a straight road can seem intricate when it involves crossing at intersections:

"The fact that at an intersection you cannot go straight ahead immediately, but have to turn off first] makes it more complicated, so in your mind you cannot draw a straight line right away" (P1).

UNRELIABILITY OF MAPS

Because environments constantly change, VIPs need to regularly update their cognitive maps (Banovic et al., 2013), further increasing the mental strain of remembering spatial representations of environments that are important in the daily life. For these reasons, VIPs often remember routes as a sequence of landmarks: environmental elements that help them determine their position. This approach saves them significant effort compared to memorizing the entire spatial layout of routes.

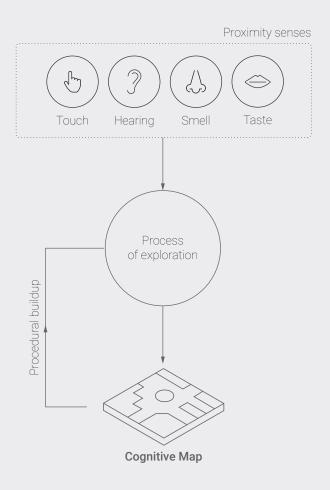


Figure 2.3 Cognitive maps of environments consist of all sorts of cues

ORIENTATION

Orientation is a very important topic in mobility. It involves understanding one's position, direction, and movement in an environment. This process depends on a combination of a detailed cognitive map and perceiving and recognizing elements in the environment:

Your personal knowledge of the surroundings plays a key role in transforming observations into useful landmarks. For example, the sound of a busy road, the scent from a bakery and sounds of people chatting on a known terrace can become navigational landmarks from which a VIP can further orient themselves. As mentioned above, prior knowledge greatly aids in forming a mental map. The more a person knows about their environment, the more freely they can move within it (Royal Visio, 2022).

P3 explains how she uses landmarks and her hearing to orient herself:

"At the building where I work then, there's an aviary with birds. That's a really good landmark. If I hear those, then I know I'm close by."

She also explains how she can use these landmarks to find her way back:

"When I walk with people, it helps if they tell me about details in the environment. Then when I come across that, I know I have to walk back this way and that way." Sighted individuals have an advantage in orientation, as they can easily spot landmarks from a distance and grasp spatial relations. They can add unfamiliar areas to their mental map based on distant landmarks. VIPs, however, have more limited access to landmarks for self-orientation. They rely on tactile landmarks, such as electrical boxes along their route, sounds, like a zoo, or smells, like a bakery, to confirm their location. This process requires intense focus and energy, and losing self-orientation can make it hard for VIPs to return to familiar territory.

As outlined by Passini et al. (1986), VIPs rely on a combination of small-scale reference points (such as posts, fences, and trees) and larger-scale landmarks (like buildings and newspaper stands). However, the challenge lies in the fact that these features are perceptible only at close range, requiring VIPs to rely on multiple reference points. This process is further complicated by the variability and unreliability of auditory and olfactory cues.

It is interesting to note that that cognitive mapping and self-orientation are interdependent. Orientation is required to know where to add new information to the mental map. Conversely, orientation relies on the mental map for recognizing and locating environmental elements or reference points.

MOVEMENT

Effective movement relies heavily on accurate orientation, which is about more than recognizing landmarks. It involves maintaining a constant awareness of one's path, location, and the relative movement of environmental elements.

Sighted individuals receive continuous visual feedback as they move, allowing them to adjust and calibrate their movements in relation to the changing environment. This feedback is crucial for making precise movements and turns. To understand the importance of visual feedback, a sighted reader can try walking a specific distance in a straight line and then turning 90 degrees with closed eyes. They will find that performing these tasks accurately is difficult without visual cues.

VIPs, who lack such visual feedback, depend on proximity senses to calibrate their movement. The most important strategy to maintain a wayfinding direction is to use the white cane to follow guidelines: rectilinear features in the environment such as walls, edges of the sidewalk or fences. Vips therefore prefer a place where they have objects and boundaries as reference over a large open space, which contains fewer paths." (Williams et al., 2014, Passini et al., 1986).

P1: "In large open spaces, I can deflect and then lose my way because I 'hear' an exit that is actually the wrong one or find a guide line that leads to the wrong exit. A large open space is tricky because you have few landmarks and guide lines."

This reliance on physical geometry for wayfinding means that VIPs cannot freely cross open space; they are confined to following the edges of the space or other tangible guidelines, which significantly limits their freedom of movement.



Figure 2.4 Without tactile reference in the environment, orientation is difficult for VIPs

MOBILITY PROCESS OVERVIEW

Thus, during wayfinding, two interactive/interdependent processes happen:

• Mental mapping: as one navigates through a (new) environment, they simultaneously construct, expand (i.e. add new space and elements to it), or update their mental representation of this environment. To understand where to add new elements in the mental map or where to update the mental map upon perception of the environment, self-orientation is required. Self-orientation: based on perceived movement and recognition of elements from the existing mental map, orient themselves within their mental representation of the environment and the world. Self-localization based on recognized environmental elements requires an existing mental map of the environment.

The mental map and orientation then allow for spatial problem solving: Based on an understanding of one's own orientation and movement and understanding of the spatial layout, the location of the goal a plan for movement through this environment can be formed.

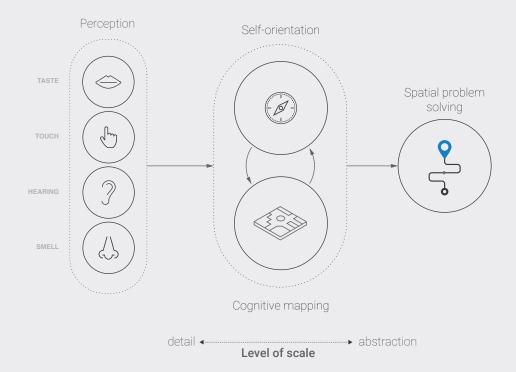


Figure 2.5 The process of mental mapping, self-orientation and spatial problem solving

MENTAL SCALE

The concept of "mental scale" in mental mapping and orientation varies and is crucial for VIPs. This concept involves multiple levels of awareness and representation, from broad cityscapes to immediate surroundings.

- Mental map at different scales: VIPs
 create mental representations of both large
 and small areas. For instance, they might
 have a mental image of an entire city for
 route planning and a detailed picture of a
 sidewalk to navigate around obstacles.
- Orientation at different scales: Orientation requires awareness of one's position on multiple scales simultaneously. A VIP needs to know their location within a city and their exact position on a sidewalk, for example for circumventing obstacles.
- 3. Spatial problem-solving at different scales: This involves determining an adequate path, both on a macro (city-wide routes) and micro (sidewalk navigation) scale. Choosing an appropriate route through the city considering street layouts and potential blockages happens simultaneously with determining an adequate path along the sidewalk.
- 4. **Abstraction** is a key function in these processes. On a larger scale, details like pavement obstacles, crucial on a smaller scale, become irrelevant. Constantly considering small-scale details when planning larger routes would be cognitively demanding and impractical.

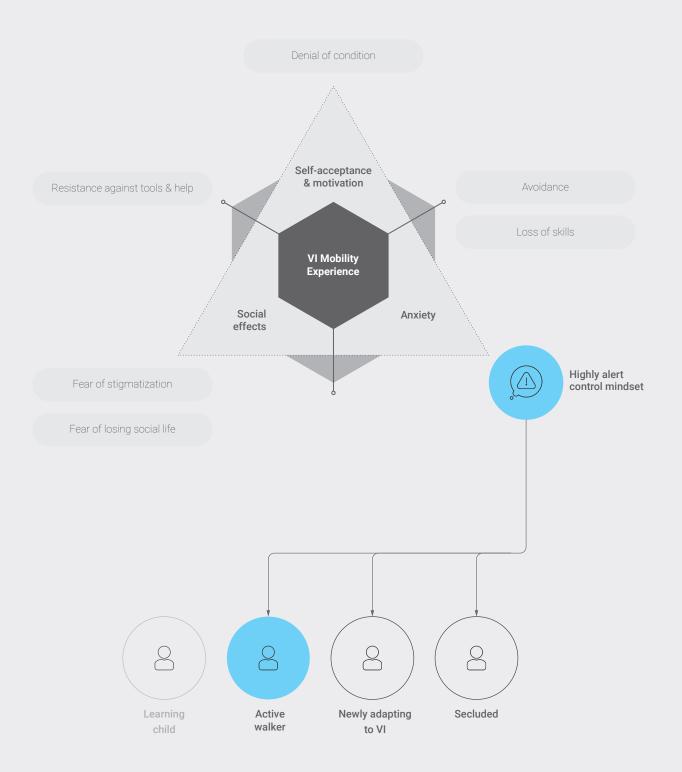
In designing assistive technology like a Dynamic Tactile Map (DTM), understanding mental scale is vital. The technology must provide information useful for both largescale navigation and precise, small-scale movements. This necessitates a high density of information displayed simultaneously which is a challenge due to inherent resolution limitations in interfaces. A critical feature for such devices therefore is the ability to 'zoom in and out', which should be well-aligned with the cognitive process during wayfinding. This is a complex requirement because in the human mind, this scaling process can occur very rapidly. To limit the requirement of automatic scaling, the interface's resolution should be as high as possible, keeping in mind the capacity of the fingers to read small details, and allow the user to choose on the map's scaling themselves.

2.3 MOBILITY EXPERIENCE

The experience of mobility goes beyond spatial capabilities, and is strongly influenced by psychosocial effects. This section delves into the deeper layer of VI mobility, exploring how the vision impairment influences not only the way VIPs move but also how they feel and how they perceive their environment. This research sheds light on the less visible but equally significant impact of the vision impairment on the process of mobility, its experience by the VIP, and even on their life, highlighting the importance of addressing these aspects in the development of assistive technologies. This research is driven by the questions:

What psychosocial factors influence the mobility experiences of VIPs, how do these factors shape their lives, and which ones are interesting for the design of new assistive solutions? The study uncovers a wide range of psychosocial themes affecting VIPs' mobility, along with distinct subgroups within the visually impaired community, each with unique needs, that provide a compelling context for design. A summary of these themes and groups is presented in figure on the right.

The design focuses mainly on the aspect of fear and alertness that results from the visual impairment during mobility. The specific needs and impacts within this topic present a fascinating challenge for the future expansion of the design. These topics are briefly discussed, with a more comprehensive explanation of this theme, the other identified themes and the subgroups available in Appendix D.



HIGH ALERTNESS AND VIGILANCE

The phenomenon of heightened vigilance among VIPs during mobility is a significant aspect of their navigation experience. This mental state, characterized by increased alertness and focus, is primarily geared towards risk-avoidance and identifying potential hazards. The origins and impacts of this heightened state of vigilance on VIPs' mobility experience are discussed in this section.

THE ORIGIN OF VIGILANCE

It is seen how the lack of overview turns tasks that require little effort for a sighted person into tasks that require mental effort and concentration. A lack of confidence in the ability to avoid hazards and fear to lose the way lead to a state of heightened vigilance, in which the VIP is primarily focused on avoiding risks and maintaining their orientation.

P1: "Before my visual impairment, walking was almost like sprinting for me. But now, I have to walk slowly; otherwise, I'd bump into everything."

P3: "I fell down from the train platform once. After that I immediately went to arrange assistance with the railway company, and I didn't dare to travel alone for a while either."

P7: "My biggest fear is getting lost or stuck somewhere. I got stuck behind a fence for a while, and I couldn't get back to the building. (...) Sometimes it's kind of like a maze."

The vigilant state of mind that limits VIPs in their freedom and lead to a disengagement from their environment comes from a lack of spatial overview and the resulting difficulty in orientation and path preview.

P5 explains how the absence of fences next to a canal next to his home leads to him always having to pay close attention: "When I walk through the city, there are trees, there are cars along the canal. But here there is nothing at all next to it. There's no poles or lane posts or a railing or anything, you can walk right into it. It would be the nicest thing if you could come and walk up between here. And then a tool would say: 'keep left, right is a moat.'"

P1: "Eventually, you do want to move toward efficiency and easier fast running. A better spatial understanding is what you need to achieve that."

THE EFFECT OF VIGILANCE

VIPs often avoid new places due to these challenges and feelings of vigilance, and stick to on familiar routes. This is confirmed by Brouwer (2008), who finds that VIPs found this "restrictive and frustrating, but it reduced their contact with unexpected obstacles to an acceptable level." This limited overview and heightened vigilance can diminish their confidence in exploring new areas, lead to a reliance on known paths, and potentially isolate them from the community. P1 explains that he avoids walking new routes as much as possible, and that he never walks an unknown route just for fun; he has a well-known route that he takes if he wants to take a walk.

P7 explains that he would wish that he had a more flexible mindset different mindset: "Weet je, dan denk je van nou, die bus komt niet. Ik pak wel een volgende, of Ik ga wel een stuk te voet, of ik weet wel dat ik niet verdwaald ga worden. (...) Ik ben er weer de typische control freak die alles moet dichttimmeren om ervoor te zorgen dat er niks fout kan gaan."

P7: "If you know you can't get lost, then you're naturally going to be a lot more flexible and have the courage to 'just take that route' if you want to."

Also, this state of mind severely reduce the VIPs ability and willingness to perceive or engage with the broader environment, and finds the VIP often disengaged with their environment. Their environmental perception and interaction with the environment is only functional.

P1: "While walking, my current path is the only thing that is important."

P5: "I know where I walk, because I walk there often. I always walk here with my dog,

but I don't know what the houses look like. I don't know if there are pointy roofs or front gardens. I do miss that: What kind of front doors do people have? That's kind of fun to see right?"

These effects are widespread and, in a large scale study in 1992, Beggs even finds that the fear of danger, a sense of lost control, and the necessity for constant vigilance are the **predominant emotions during mobility** for VIPs.

The concept of a dynamic tactile map that enables a more comprehensive overview of the surroundings is not only important for more effective orientation and wayfinding, but its deeper value lies in enhancing users' confidence and sense of safety, and reduction of the fear of getting lost. This, in turn, allows users to better engage with and pay attention to their environment, and consequently allows them to divert their attention to and engage more fully with their surroundings.

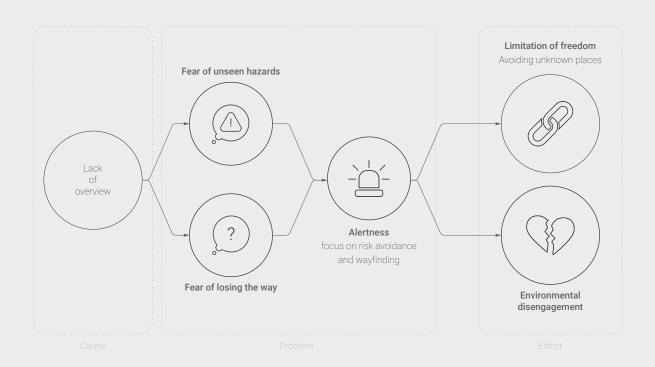


Figure 2.7 VIPs often need to pay close attention to avoid getting in danger, or getting lost

2.4 CONCLUSIONS

The primary mobility challenge for VIPs is their limited ability to accurately perceive from a distance and comprehensively overview their environment. This lack of a clear environmental overview hinders their navigation capabilities, making it difficult for them to recognize destinations, identify obstacles, and avoid potential hazards. Consequently, VIPs must rely heavily on mental mapping and memorization, which makes environments seem overly complex and turns mobility in a cognitively demanding process. Furthermore, the lack of environmental overview leads to fears of unseen hazards and losing orientation, which reduces freedom and flexibility, and leads to a vigilant state of mind that reduces the VIP's engagement with the environment.

By providing an enhanced spatial overview, such technology enables VIPs to better understand and navigate their environments. It allows them to orient themselves spatially and move more freely. Furthermore, a better spatial understanding and path preview can

reduce the need for vigilance, avoidance of new environments and overpreparation, enabling VIPs to travel with more confidence and spontaneity. This enhancement not only facilitates mobility but also encourages exploration and interaction with their environment, transforming travel from a mere functional activity into an enriching experience. Herein lies the transformative potential of the Dynamic Tactile Map for improving the mobility capability, experience and overall quality of life for VIPs.

DESIGN IMPLICATIONS

RELIABLE DISTANCE PERCEPTION

The DTM should provide accurate distance perception that enables a comprehensive spatial overview of the environment, aiding in spatial orientation and problem solving. It should facilitate the formation of mental maps of spaces, including environmental structures, routes, and landmarks.

REDUCE ALERTNESS THROUGH OVERVIEW

The environmental overview should allow participants to easily maintain their orientation, requiring a less strong focus on not losing the way, and through the experience of an overview of the environment and preview in the path ahead it should decrease the fear of unseen hazards.

DYNAMIC PERCEPTION TO FREE MOVEMENT

The dynamic map should enable VIPs to move based on their distant perception of the environment, allowing them to 'calibrate' their movement based on the perceived relative movement of the environment and allow users to perceive and react to changes in their surroundings in real-time. This empowers VIPs to move freely across space without reliance on the guideline.

SUPPORTING DYNAMIC MENTAL SCALE

The process of changing mental scale is important in the design of the environmental representation. The interfaces resolution, zoom level and resulting abstraction of smaller scale details should be carefully considered. The elements that are relevant to show in an environmental representation depends strongly on the current 'mode' of operation and differs strongly per mental scale, an this topic should be extensively researched lateron, when a working prototype of the DTM is available.

INCREASING ENVIRONMENTAL PERCEPTION AND EXPLORATION

Increased stimuli through a comprehensive and vivid environmental perception encourage greater awareness, engagement and interaction with the environment.

3 EXISTING ASSISTIVE SOLUTIONS

The range of assistive solutions available to visually impaired individuals reflects both progress in technology and the gaps in meeting their real needs. This section critically examines existing tools, from traditional aids

like canes and guide dogs to modern digital technologies. It underscores the limitations of current solutions and sets the stage for a paradigm shift towards more holistic and effective assistive technologies.

3.1 TRADITIONAL SOLUTIONS

The white cane and guide dog are the most prevalent and recognized tools for mobility assistance, known for their simplicity and effectiveness, supported by organizations like Bartimeus and Royal Visio. Despite their long-standing use, they remain the sole primary tools, independent of other aids.

This design project aims to create a primary tool that could potentially replace or enhance these traditional methods. Understanding the limitations and functions of the white cane and guide dog is crucial for developing a solution that offers significant value.



Figure 2.1 The white cane and Guide dog

WHITE CANE

The white cane comes in two types:

- the short signaling cane, used to alert others to the user's visual impairment,
- and the more common long cane, which acts as an extension of the arm during walking, providing tactile and auditory feedback from ground textures, as seen in figure 4.2 below, while also signaling the user's impairment.

This signaling function is vital, and carrying a white cane is often a requirement by insurance companies. Given the project's goal to design assistive technology that replaces the white cane, incorporating its signaling function becomes a critical design requirement:

This new technology must effectively communicate the user's visual impairment to surrounding traffic participants, ensuring safety and compliance with insurance standards. Although an important topic, this is kept out of scope during this project. This is further discussed in the conclusion of this chapter.

The white cane, while a reliable tool for enhancing environmental perception, has notable limitations. Its perceptive range is limited to about one and a half meters, focusing only on the immediate vicinity around the user, as seen in figure 4.2 below. Its effectiveness is tied to the speed at which the user moves the cane, making it challenging to maintain a complete perception during rapid movement. Mastering its use also requires significant training and regular practice.



Figure 2.2 Perceptive range of the long cane

GUIDE DOGS

Guide dogs assist VIPs by helping them navigate and perform tasks like avoiding obstacles and locating landmarks. They also help to locate landmarks, such as stairs, doors, and elevators. While having a guide dog can make mobility more carefree, it is not a viable option for everyone. Ownership requires the commitment of caring for a dog, and the process of training such specialised dogs is both time-consuming and costly, resulting in guide dogs only being available in wealthier nations (Chanana et al., 2017).

In this partnership, the VIP provides instructions, and the dog leads the way. If the dog knows its destination, it can guide the VIP there quite efficiently. However, the dog does not know the way, and in new environments, however, the dog depends on the instructions of its owner, such as "Find the elevator", or "Find the exit". This delegation of control can be both relieving and a source of inflexibility or uncertainty. For instance, a VIP may unintentionally be led to a wrong location without being aware of it.

P2 gives a vivid description of such a situation: "I get off the train in Utrecht.

Utrecht has long platforms, so you have to know which way to go. I walked with my dog Dapper in the direction of the stairs, but the stairs stayed away for a long time. At a certain moment he stops, indicating that we must be at the stairs now. So I say, "go down", and he didn't do it. Well, I found only later that I was at the end of the platform.

After three commands he was prepared to go too, but then he stood on the rails. You can't ask the dog: wat is wrong, why don't you walk on?"

This example underscores the VIP's complete reliance on the dog for orientation and the risk of being unknowingly led astray. Similarly, P3 observes that deviations from familiar routes can lead to confusion or reaching the wrong destination. In such partnerships, training the dog on new routes is essential to prevent these issues.

The change in mobility that results from the adoption of a guide dog style impacts awareness of surroundings. The VIP is less busy with actively getting to know the environment, which results in a less comprehensive mental map of the environment. Also, because they need to hold the guide dog, it is more difficult to scrutinize the environment with the cane, and relies more on proprioception, makes orientation more challenging. As P1 explains:

"With the dog, you walk differently. You cannot recognize your landmarks with the stick, you have to orient yourself based on what you feel with your feet, and that is difficult. It is more relaxed, though, because you are less afraid of obstacles."

3.2 CONTEMPORARY ASSISTIVE TECHNOLOGIES

The landscape of assistive solutions for VIPs has witnessed significant technological advancements over the past half-century. These innovations represent a spectrum of tools and systems designed to enhance mobility and independence, addressing some of the limitations inherent in traditional aids like the white cane and guide dog. This section examines these contemporary technologies, examining their role not just as additions to, but also as potential alternatives to their traditional counterparts.

This analysis highlights how advancements in digital technology, such as sensor technologies and artificial intelligence (AI) have been leveraged to create more effective assistive tools. This finding, however, sets the stage for a critical inquiry:

Despite the progress, why do traditional tools like the white cane and guide dog continue to be the only primary aids?

The chapter explores various categories of modern assistive technologies. These include instruction-based systems that transform environmental cues into navigational instructions, advanced technologies that enhance environmental awareness through AI and AR, and tactile maps that aid in providing spatial understanding. Each category will be examined not only for its functional/technological merits but also for its impact on the experience of mobility.

The goal of this exploration is twofold: to appreciate the improvements offered byassistive technology and to critically assess the extent to which these innovations have truly transformed the mobility and independence of visually impaired individuals. The understanding the strengths and limitations of these contemporary solutions, leads to a vision for a future-proof approach to the development of assistive technology — a future that hopefully bridges the gap between technological potential and the real-world needs of VIPs.



Figure 2.3 Mobility of VIPs, then and now

INSTRUCTION-BASED ASSISTANCE

Instruction-based assistive technologies have emerged as significant tools in the arsenal of aids VIPs. These technologies, primarily focused on navigation, provide the user with auditory or tactile instructions, based on their knowledge of the uesr's location and their environment, guiding users through their surroundings.

Traditional indoor navigation systems
 use beacons or barcodes installed in
 environments. These systems guide users
 through these prepared environments by
 providing navigational information as they
 pass strategic points marked with barcodes
 or beacons.

 GPS navigation technologies like BlindSquare (as seenin the image by St. Albert Gazette below) and Apple Maps use GPS data to track the user's location, providing auditory instructions to navigate the external world. Such apps have revolutionized how VIPs travel, offering them a greater sense of independence by enabling them to navigate unfamiliar areas without memorizing entire city layouts. However, while these apps have been invaluable in broadening the horizons of VIPs, they predominantly offer route guidance without conveying a comprehensive sense of the surrounding environment.

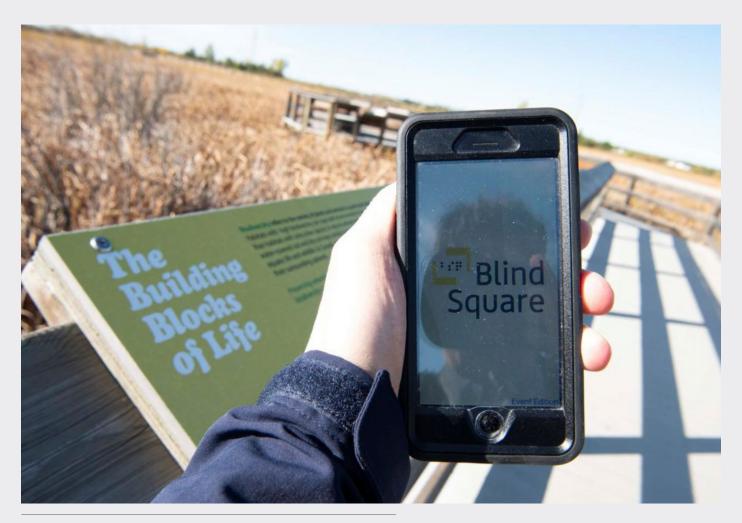


Figure 2.4 Blindsquare provides navigation instructions in all sorts of environments (St. Albert Gazette)

LIMITATIONS

The primary limitation of instruction-based assistive technologies lies in their approach to environmental interaction. By abstracting the environment into a set of instructions, these technologies often leave the user without a more elaborate awareness of their surroundings. This can lead to a sense of uncertainty or incomplete spatial awareness, despite the navigational assistance provided. For instance, P5 explains how Blindsquare provides him with the necessary navigational instructions, but it does not alert him of the large canal that is next to him:

"You hear the intersection Sint-Margetenstraat, but is not exact. He doesn't say there's a canal. So if he says Sint-Margetenstraat, and I would walk to the left for a moment, I could fall into the canal. I miss that in that navigation." Moreover, an over-reliance on these technologies can result in a form of passive navigation, where VIPs follow instructions without actively engaging with their environment. This approach can reduce the user's autonomy in making movement decisions and limit their opportunities to interact with and learn about their surroundings.

In conclusion, while instruction-based assistive technologies have made significant strides in enhancing the mobility of VIPs, their reliance on providing navigational instructions, rather than a rich spatial understanding of the environment, means that they can only supplement rather than replace traditional tools like the white cane and guide dog. The challenge remains to develop technologies that empower VIPs to have a more comprehensive awareness of their environment.



Figure 2.5 Navigation instructions (Siemens Knowledge Hub)

TECHNOLOGY FOR ENVIRONMENTAL AWARENESS

Advancements in technology have enabled the development of assistive devices that enhance environmental awareness for VIPs. These devices employing cutting-edge technologies like 3D cameras and artificial intelligence (AI) to provide a the user with more information about their surroundings, leading to more informed and independent decision-making during mobility.

• Scene recognition technology, often integrated into wearable devices such as the Orcam (Orcam, 2023), analyze information from their cameras with Al-algorithms and describe relevant information through audio. For example, they can identify and verbally describe objects, people, and text in the user's vicinity. This technology provides VIPs with

- information about their surroundings upon request or at regular intervals, aiding them in understanding their location and the elements within their environment.
- Indoor navigation technologies such as
 Goodmaps use AR technology to provide
 the user with auditory descriptions
 descriptions of the indoor space, helping
 VIPs navigate complex areas such as
 shopping malls or airport. These systems
 often rely on pre-mapped environments and
 provide. While this technology represents
 a significant leap in assistive solutions,
 its use is restricted to pre-scanned
 environments.
- Some GPS navigation technologies
 have evolved to offer more than just
 directional guidance. For instance, apps
 like BlindSquare (Blindsquare) now
 announce information such as the name



Figure 2.6 Goodmaps helps navigation in pre-mapped environments

of the nearest street or points of interest.

This feature, while basic, contributes to a greater understanding of one's location and immediate environment.

 Obstacle detection systems, often wearable or integrated into devices like smart canes, use sensors to detect obstacles in the user's path, essentially 'extending' the white cane's reach. When an obstacle is detected, these systems alert the user through vibrations or auditory signals, effectively 'steering' them away from potential hazards.

LIMITATIONS

Despite these significant technological improvements, there are crucial limitations to address. A primary concern is the 'black box' experience (Lanting, 2023). Users often fear that such technologies might overlook critical details due to the intransparant nature of AI decision-making processes. This uncertainty can damage trust in the technology, as VIPs cannot ascertain what the device perceives or how it interprets their environment.

Another fundamental challenge is the

constraint of the interfaces used by these technologies. While auditory interfaces are beneficial for conveying certain types of information, they are markedly inefficient in communicating spatial information. For effective wayfinding and mobility, spatial information is crucial: mobility problems are often of spatial nature (Passini et al, 1986). As observed by Athulya et al. (2023), contemporary navigation technologies do not provide a comprehensive perception of the environment, and for example incorporating an overview of the terrain would allow for a better travel experience. When attempting to communicate such complex environmental data through audio alone, this might lead to sensory overload, the overwhelming of the senses.

To truly enhance the mobility and independence of VIPs, assistive technologies require interfaces capable of delivering dense spatial information without overwhelming the user. This calls for a shift towards developing solutions that can communicate a more comprehensive environmental overview through spatial information, enabling safe, effective, and confident mobility.

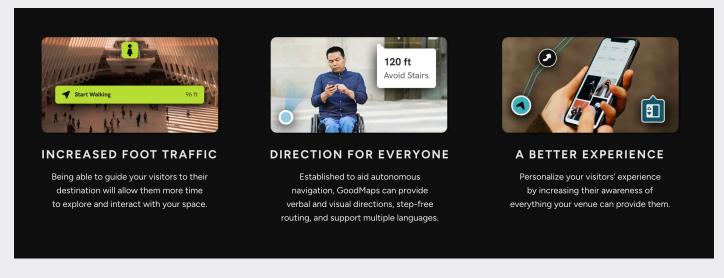


Figure 2.7 Goodmaps helps navigation in pre-mapped environments

THE TACTILE MAP

The tactile map, an often-overlooked but vital component in the array of assistive technologies for VIPs, presents a unique approach to conveying spatial information. Unlike the auditory-focused technologies discussed earlier, tactile maps offer a physical representation of spaces, allowing VIPs to 'feel' their environment with their fingers. These maps exist both in 2D, such as raised-line maps and 3D, which represent the actual landscape and its relief. They serve as an essential tool for pre-travel preparation or onsite navigation, particularly in public spaces like train stations or city centers.

Much research exists that counters the misconception that blind people mentally understand spatial environments. Studies, like Passini et al. (1986), show that blind individuals can form spatial representations and navigate effectively through it once they understand a layout. Papadopoulos (2020) shows that tactile maps are are especially useful in this process, effectively helping VIPs understand detailed spatial layouts.

A significant advantage of tactile maps is their ability to present detailed spatial relationships in a tangible, multidimensional format. This approach effectively communicates complex environmental information without causing the sensory overload that other mediums might, making them an invaluable tool for conveying spatial relationships and layout understanding

Despite their advantages, tactile maps have their limitations. The availability and accessibility of updated tactile maps can be a challenge, particularly for less common or rapidly changing environments. More importantly, their static nature means they are most useful for familiarizing oneself with a new environment but less so for real-time navigation. Moreover, they are typically limited to representing fixed elements of the environment and, by nature, cannot convey dynamic environmental elements.

The development of dynamic tactile displays allows for real-time updates and more interactive exploration of tactile maps. Some of these innovative solutions can transform digital data into tactile formats, providing VIPs with up-to-date information about their surroundings.

THE DYNAMIC TACTILE MAP

the future of tactile maps lies in the integration of the benefits with the earlier-mentioned technologies that apply cutting-edge sensor technologies and algorithms with the capabilities of the tactile map to provide a more comprehensive spatial overview. By combining the detailed spatial information of tactile maps with the real-time updates and comprehensive context-awareness of these technologies, it's possible to create a more holistic assistive solution. Such integration could offer VIPs a richer understanding of their environment, enhancing their ability to navigate independently and confidently.



Figure 2.8 Tactile maps provide spatial representations through simplified representations (TomTom, 2022)



Figure 2.9 Tactile maps can also convey 3D landscapes (TomTom, 2022)

3.3 GENERAL TOPICS

Additionally, interviews with field experts, further detailed in Appendix E, have uncovered significant insights worth highlighting:

AVOID TECHNOLOGICAL OVERLAP

Smartphones have replaced many standalone devices. Their ability to centralize various functions into a single device simplifies interactions compared to using several gadgets. This is particularly beneficial in situations where hands-free operation is essential, like climbing stairs. More often than not, smartphones are already carried by VIPs, ensuring that the VIP can always rely on its availability. In contrast, standalone tools are more prone to being forgotten or intentionally left behind, reducing their reliability (Lanting, 2023).

This shift has significant implications for designing assistive technology. Instead of introducing new, separate products, it's more effective to consider technology as an integrated platform. For instance, as the dynamic tactile map aims to enhance environmental awareness for VIPs, logically, it should incorporate other functionalities like navigation and public transportation services. This integration not only strengthens the business proposition but also aligns more closely with user needs for a unified solution, easing the travel process.

However, the topic of navigation and the integration of other applications in a platform is kept out of scope of this project due to time limitations. navigation is very important, that the focus of this project is on extending perception, effectively reducing the need for navigation in smaller scale and environments (sighted people also do not need to get navigation instructions to find their way through a hospital, for example). This topic is further discussed in the discussion section.

Moreover, if users already utilize certain mainstream technologies, new products should have as minimal overlap in their functionality and technology as possible and opt for integrated solutions. Integrating solutions with existing technology ensures VIPs don't need to carry extra devices, streamlining the product. This concept gains further relevance, as discussed in Chapter 8 - Tactical Roadmap, where it is identified that future spatial computing systems like augmented reality glasses that might be mainstream technologies by the time could take over the function of environmental mapping required for the DTM.

DESIGNING THE LEARNING PROCESS

Many assistive products promise significant mobility improvements but their effectiveness often depends on the user's ability to proficiently use them, which in turn depends on adequate training. Unfortunately, manufacturers frequently overlook the importance of this training process or fail to provide sufficient support. Consequently, users, burdened with high but unmet expectations, may experience disappointment and distrust in the tool, leading to underuse of products that actually have much greater potential (Lanting, 2023).

A notable exception is the BiPed's gamified learning approach. Here, users progressively 'unlock' advanced functionalities by achieving specific milestones, ensuring they are introduced to more complex features only after mastering the basics. This method not only makes learning more enjoyable and engaging but also encourages practice and improvement (Wienholts, 2023). Although the BiPed is still under development with its long-term effectiveness yet to be confirmed, its approach is promising for this project. Integrating such a gamified learning curve can enhance user engagement, build trust, and make the learning process more effective, aligning with the goal of creating user-centric and engaging products. Given the project's conceptual nature, incorporating a thoughtful and progressive learning curve is highly recommended for future development.

PORTABILITY AND HANDS-FREE USE

Mobility products are preferably used while the user is moving, without requiring them to stop to gather or process information. A significant challenge in developing mobility products is the fact that at least one hand is often already occupied by a white cane or a guide dog's harness. This means that new products either need to work in tandem with these existing tools or replace them, allowing one hand to remain free for essential actions. To address this, many mobility products are being designed as hands-free, wearable devices, for example head-worn or integrated into clothing, allowing for the simultaneous use of a cane or guide dog (Wienholts, 2023).

This project aims to design a concept that is used as a standalone, so the combined use with a white cane or guide dog is irrelevant. However, it does results in the requirement for the product to allow at least one hand to interact with the environment, when necessary.

INCREASINGLY DIRECT PRODUCT PURCHASE

Increasingly, Consumers are increasingly purchasing products directly rather than obtaining them through traditional mobility aid suppliers in combination with a recommendation from a specialist or general practitioner, attesting to the necessity of the device due to a visual impairment, to have the product covered by insurance or subsidies. Additionally, it is often not possible to request multiple products within the same category, and the specific organization through which to obtain the aid depends on the type of device. In some cases, an occupational therapist specializing in a particular area may need to be involved (Mark Lanting).

Given this shift towards direct consumer purchase (whether subsidized or not), might be that future users will buy the product themselves instead of receiving it through a professional prescription. This change has significant implications for product marketing strategies and product pricing. Marketing efforts should be more user-centric, targeting the end-users directly rather than focusing on professionals in the field. Due to the conceptual status of this project, this shift in marketing approach is recommended as a future consideration. Understanding the user's needs, preferences, and buying behaviors will be essential in effectively reaching and engaging them.

THE SIGNALLING FUNCTION

Integrating a signaling function into the Dynamic Tactile Map system is crucial for the safety of VIPs, especially as it aims to replace the traditional cane. This feature alerts others to the user's visual impairment, a requirement often mandated by insurance companies for VIPs' mobility. Designing this signaling mechanism requires considering the perspectives of various stakeholders, including insurance agencies, regulatory bodies, and most importantly, VIPs. It's essential to ensure the new method is comfortable and stigmafree, as discomfort and social stigma are significant barriers to technology adoption. Given the complexity and importance of this issue, the signaling function will not be addressed in the current project phase but should be a priority in the technology's further development.

3.4 CONCLUSIONS

This chapter underscores the need for a paradigm shift in the design of assistive technologies for VIPs. Future designs should aim to provide a richer, more comprehensive environmental understanding to enables users as independent, confident spatial actors capable of their own decision-making. The integration of traditional tactile maps' benefits with cutting-edge sensor technologies and algorithms applied in modern assistive tools could lead to technologies that offer real-time, detailed spatial information. Such innovations promise to elevate the level of independence and quality of life for VIPs beyond what current tools can achieve. The following section will elaborate on this design vision. This analysis leads to the design vision described in the following section.

This means that in the design of the DTM, the focus will not be on creating a navigation tool that steers VIPs through an environment, but rather on a perception tool that allows them to steer themselves. It is recognized that for large-scale navigation, like city-wide travel, a navigation application would still be required, however this aspect falls outside the current project's scope. The integration of such a navigation function remains a significant consideration for future development, as highlighted in the recommendations for future advancements.

4 DESIGN VISION AND GOAL

This section maps out the design space, informed by the comprehensive research of the VI mobility challenge, and details the transformative vision and goal for the design of the novel assistive technology, the design phase of which starts in the next phase.

4.1 PROBLEM SPACE

The identified problem space is multifaceted, combining perceptual, cognitive, and emotional challenges.

LIMITED DISTANCE PERCEPTION

A limited distance perception limits VIPs' ability to mentally overview of their surroundings. VIPs often struggle with perceiving and understanding spatial layouts and distant obstacles, which is crucial for safe and effective navigation.

IMPLICATION

This leads to an over-reliance on proximate and tactile cues, limiting their ability to anticipate and prepare for upcoming environmental changes.

This impacts their wayfinding capabilities, orientation, their experience of mobility and overall engagement with their surroundings.

DEPENDENCE ON MENTAL MAPPING

Due to this limited environmental overview, VIPs rely heavily on mental maps stored in their memory. The formation of such mental maps requires a comprehensive structured search in which the VIP needs to traverse space in order to be able to map it. This process is demanding, and the cognitive maps are often inaccurate and incomplete, and can be outdated.

Self-orientation becomes difficult and requires deliberate attention due to the reduced access to landmarks. Movement is dependent on the guideline due to the inaccessibility of spatial feedback from the environment requires for calibrate of one's own movement, and a lack of preview in the path ahead and potential upcoming hazards requires the VIP to scrutinize their path for potential dangers and avoid accidents.

IMPLICATION

The process is susceptible to errors, especially in dynamic or unfamiliar environments, leading to disorientation and increased cognitive load.

VIGILANT STATE OF MIND

The constant need for vigilance arises from the fear of unseen hazards and losing orientation, leading to a heightened state of alertness.

IMPLICATION

This state can be mentally exhausting and limit the spontaneity of travel, leading to social isolation and reduced quality of life. It also limits the attention for the surroundings during travel, reducing their understanding of their surroundings and ability to enjoy and engagement with them.

4.2 DESIGN VISION & GOAL: BEYOND TRADITIONAL MOBILITY

DESIGN VISION

The research and analysis of current assistive technologies have inspired a transformative vision for the future of mobility aids for VIPs:

In this future, technology to not only enhances VIPs' capabilities in safe and effective wayfinding, but also enable them with a confident awareness of their surroundings. This reduces their need to be constantly alert about hazards or losing their way.

Through confidence and comprehensive understanding they can further experience, engage with and explore the world and conduct spontaneous travel.

The ultimate goal is to transform mobility for VIPs into an experience of exploration and connection with the world, and empower VIPs as independent, engaged travelers.

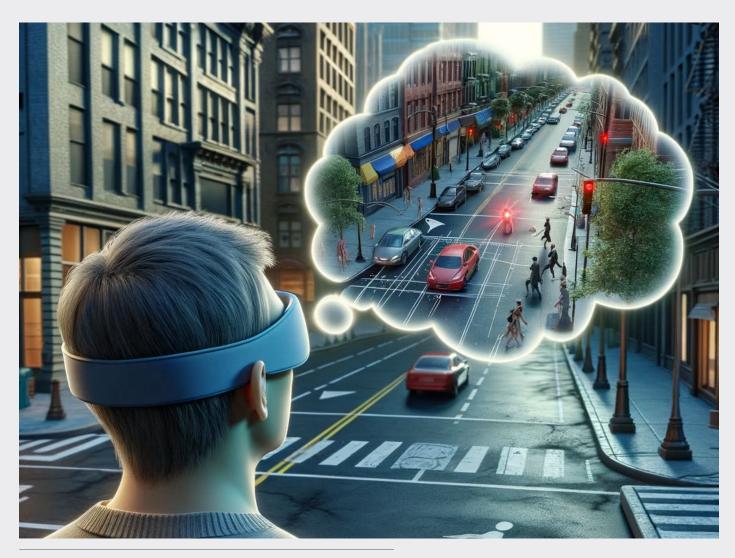


Figure 4.1 Increased environmental awareness through the novel assistive technology

DESIGN GOAL

To realize this vision, the following goals are established for the development of an assistive technology:

1. Enable comprehensive environmental understanding

Develop a system that provides a comprehensive and detailed perception of surroundings. This technology should facilitate informed and autonomous decision-making by offering nuanced insights into spatial layouts, potential obstacles, and key landmarks. This perception is both broad and detailed, allowing for both environmental overview and precise movement. It allows the user to understand spaces, including environmental structures, routes, and landmarks.

2. Enable seamless and intuitive perception

The technology should integrate effortlessly with the user's natural perception abilities. It must require minimal cognitive effort through a map representation that requires minimal mental translation, allowing for a quick and comprehensive overview of the environment. This will enable VIPs to focus more on their experiences rather than the mechanics of the technology.

3. Enable dynamic environment perception

Ensure the map dynamically adapts to changes in the surroundings, allowing users to perceive and react to changes in their surroundings. This enables them to use environmental movement as reference for their own movement, facilitating free movement across various spaces without reliance on the guideline.

4. Enable understanding of the spatial environment

The technology allows users to recognize and understand the environment, key landmarks and other important elements that are vital for effective and goal-oriented navigation and the discovery of potentially interesting places or environmental elements.

5. Elevate confidence and Independence

The technology should reduce mobilityrelated anxieties, fostering confidence and independence, transforming the user from being cautious to confident explorers of their environment.

6. Establish engagement and experience

The With this newfound confidence and capability, the door is opened for a vivid environmental experience that allows for curious engagement with/exploration of the environment.

7. Actively collaborate

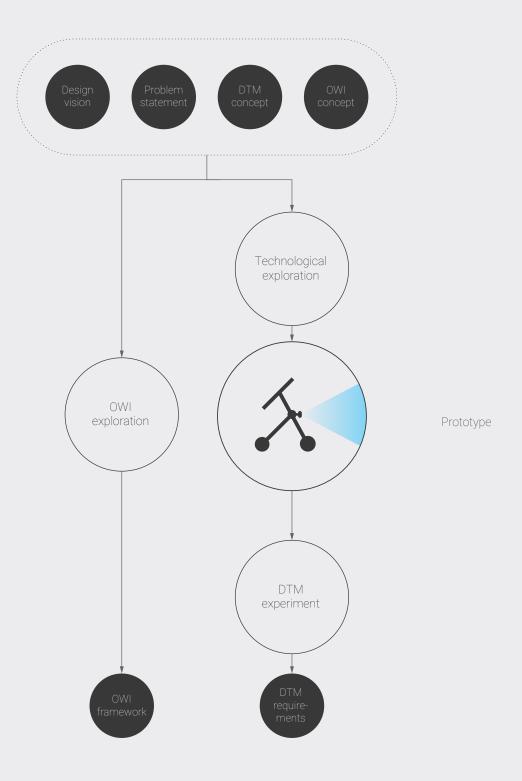
Acts as a reliable and proactive partner in mobility, collaborating with the user in their mobility process with attention to both functional and emotional needs.



RESEARCH-THROUGH-DESIGN

Based on the design problem and goals, the design of the assistive technology developed in a research-through-design phase. The design assumes two starting points: the Dynamic Tactile Map (DTM) for environmental awareness and the Object with Intent (OWI) for collaborative interaction. Development of the OWI framework and DTM research are carried out through two simultaneous experimental streams, which are brought together in the next phase.

- Experiment with DTM Prototype: A
 functional prototype of the DTM is
 developed to facilitate initial research
 into how the device aids in environmental
 perception. An experiment using this
 working prototype is conducted to gather
 insights on the experience of the DTM and
 identify areas of improvement.
- Generative Exploration of OWI: Through explorative methods such as enactment and ultra-rapid prototyping, various roles of the device as a mobility partner are explored. This aims to come to a framework of collaboration for the Map with Intent.



5 CREATING AND TESTING A DYNAMIC TACTILE MAP

This chapter outlines the development and testing of a prototype for the Dynamic Tactile Map (DTM). This prototype is a crucial step in developing the conceptual assistive technology, because the DTM's dynamic response to user movement is a key aspect of its functionality and user experience.

Although relatively simple, the prototype serves as an initial representation of the DTM concept

that allows for hands-on experimentation and gathering of valuable insights into user requirements and the challenges involved in designing for tactile environmental perception.

This phase is vital for designing a more advanced DTM and ensuring its foundation in practical user insights.



Figure 5.1 The prototype

5.1 THE PROTOTYPE

A functional electronic prototype is built at the start of this phase, as part of a **technological exploration process.** The final result of the technological exploration is a working prototype, to be used in an experiment with the concept of environmental perception through a Dynamic Tactile Map (DTM). Key objectives of the building phase are:

- Understand System Complexities: By building the prototype, insights into the complexities of the intended system are obtained.
- Identify Failure Points: Identifying potential failure points is crucial to understand their impact on the user experience and interaction with the device.

LAYOUT

The prototype for the DTM is shown in figure 5.3 on the next page. It features the DotPad, an advanced electronic Braille display with a 60x40 grid. This prototype creates real-time 3D maps using a depth camera that show a top view of its environment, distinguishing between areas that are walkable and those that are not. The map updates as the prototype moves and rotates, and users can 'look around' by rotating the prototype. The prototype is attached to a walker and includes a 3D printed frame to house the technical parts, emphasizing the users interaction with and experience of map, rather than its physical design. For more details on the prototype's construction and operation, see Appendix F.

THE MAP

The device uses a forward-facing camera to create a 3D map of the surroundings, displaying it as a top-view on the screen. The user, positioned at the bottom center of the map, sees the forward direction straight up from their location marker. Users navigate the map by feeling it with their fingers. Lowered dots represent walkable areas and raised dots display obstacles or non-walkable spaces.

As the user moves, the map updates in real time, although with a relatively low refresh rate of ~0.5Hz, aligning with their movement and orientation. New areas captured by the camera appear on the map. The device's memory stores these maps, allowing users to perceive

entire previously mapped areas, even if they are currently out of camera view.

To the left of the screen is a mechanical slider for zoom control. Moving the slider down enlarges the view to a maximum of 15 meters at the top edge of the screen, while sliding it up reduces the view to focus on a 3-meter range. The position of the slider also indicates the current zoom level, helping VIPs understand the scale at which they are viewing the map.

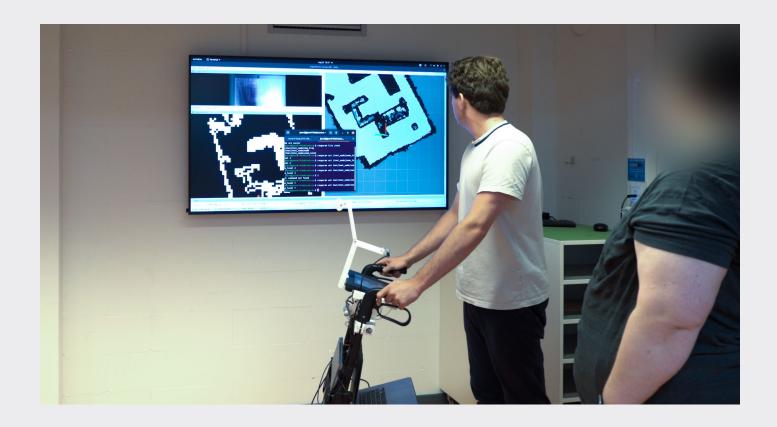
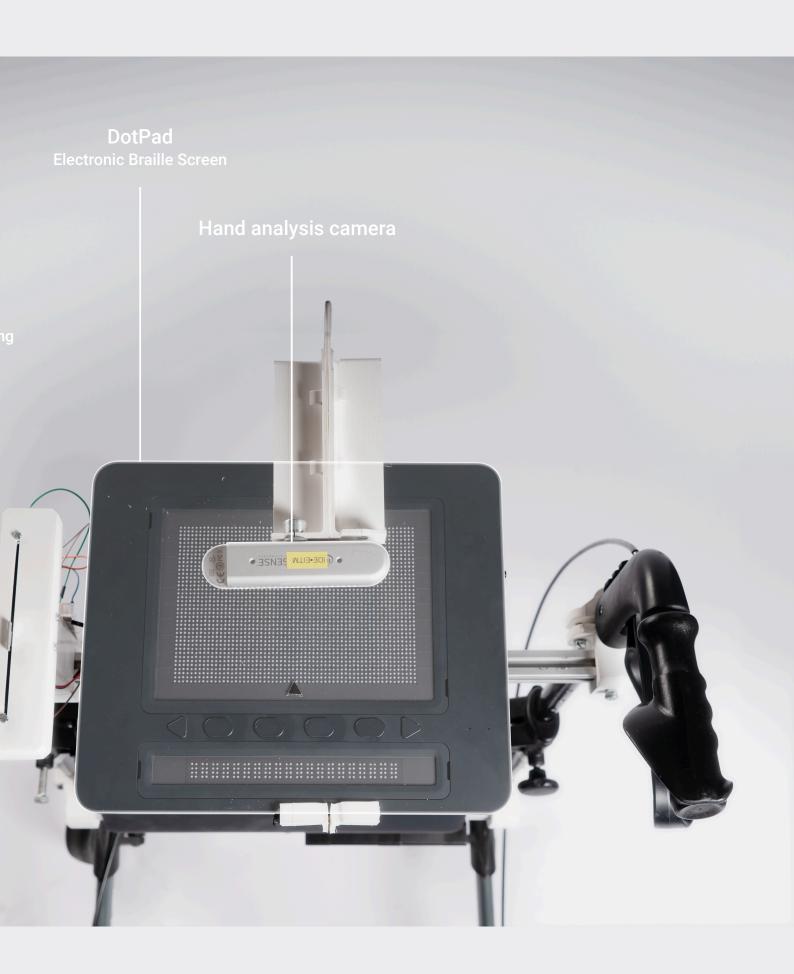


Figure 5.2 The room contained screens and a control center for control and observation of the map



Figure 5.3 The prototype's layout



5.2 THE EXPERIMENT

This section presents the experiment designed to test the prototype of the Dynamic Tactile Map (DTM). The objective was twofold:

- To assess the value that prototype already brings in its ability to enhance wayfinding, intuitive perception, and vivid communication of the environment
- 2. To find improvements on these topics for a more advanced, better version of the DTM

The experiment involved eight visually impaired individuals selected based on specific criteria to ensure a representative sample of the VIP population. The criteria included the level of

visual impairment, experience with navigational technologies, and familiarity with participating in experimental settings.

The data collection includes video recordings from multiple angles, capturing consent, interviews, and interactions with the tactile map. Three cameras document interactions for synchronized analysis. The data are analyzed qualitatively through thematic coding, focusing on user experience and prototype functionality for future development. See Appendix G and H for a more detailed description of the research setup and results.



Figure 5.4 An impression of the experiment

ENVIRONMENT AND EQUIPMENT

The experiment was conducted in a controlled, simulated environment within the Faculty of Industrial Design Engineering. This space was optimized for clear mapping by the DTM and structured to emulate real-world conditions, featuring varied layouts and obstacles to simulate common navigational challenges faced by VIPs.

The experiment revolved around the DTM prototype. This prototype incorporated the DotPad, an advanced electronic Braille display with a 60x40 grid, capable of creating real-time 3D maps of the environment. Their interactions with the prototype are recorded via a live camera feed and wirelessly monitored and controlled from a central hub for effective monitoring and control by the researcher.

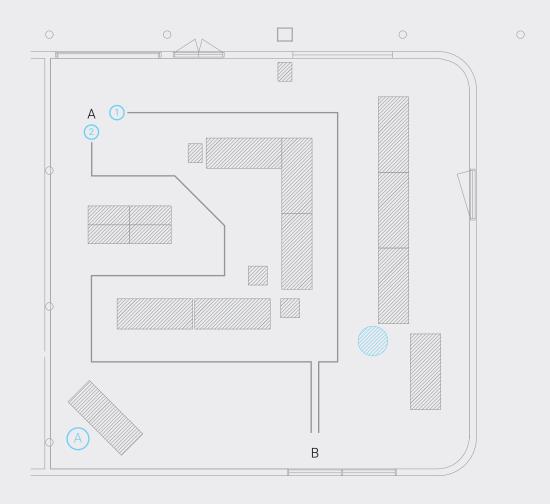


Figure 5.5 The layout and designated paths of the experiment

RESULTS

This section details the key findings, from the experiments and shows interesting interactions and topics of improvement.

ENVIRONMENT PERCEPTION

It is observed in many occasions that participants were able to understand the spatial layout of the room from different locations through the room, and plan a path through it. Spatial boundaries formed the most important information for the participants' spatial understanding, and they used the shape of the space to form an understanding of the room's spatial layout.

P3 explains how the prototype enabled (and forced) him spatially, which he normally does to a lesser extent: "Seeing that it forces you to think more spatially, navigate more spatially, I really liked that. (...) You're pushed with the stick just to think about the meter in front of you, that's literally all you have. Here you suddenly have a lot more data. You are also pushed to use that data."

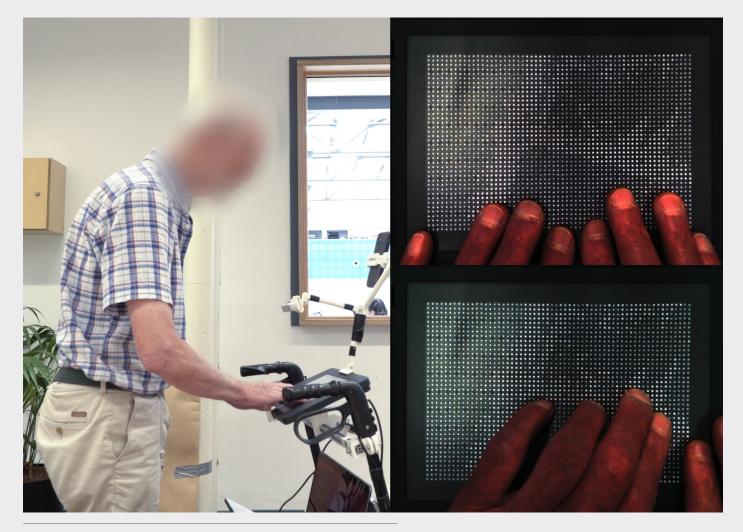


Figure 5.6 A participant forming an understanding of the space ahead of him



Figure 5.7 The Dynamic Map enabled us to talk about space that was far away

To understand the space around them, participants scanned along the space boundaries to form a spatial overview, which be seen in figure 5.6 to the left.

They were also able to perceive space that was outside of their direct path, e.g. behind a row of tables that delimited their path, and they showed their natural tendency to perceive and explore this space from afar.

P2 explains that the perception of environmental elements in the map makes him want to know what these elements are: "Ik denk dat ik in werkelijkheid zo nieuwsgierig zou zijn dat ik het zou gaan verkennen. (...) ernaartoe gaan en voelen wat het is."

This spatial thinking cost mental effort, because this is not possible with standard assistive tools.

P3 notes the difference with walking with the cane, which happens much less on spatial overview, and how this costs him more

energy: "Ik merkte toen we ermee bezig waren hoeveel energie het mij kostte. Ik zat er net over na te denken" waarom is dat? Dat is deels omdat ik continu moet verwoorden wat ik denk. Maar dat is ook deels omdat je dat ruimtelijke denken moet doen, Wat ik niet doe normaal gesproken omdat het niet kan."

The spatial overview and landmarks allowed participants to orient themselves in the space when they were able to recognize environmental elements in the map. A larger overview was key here, and when choosing between more accurate and zoomed in map and more overview, participants almost exlusively preferred the latter, to retain the context of their environment.

P2 explains how he used a cabinet that he could recognize on the map for his orientation throughout the whole room: "En voor mij was dat kastje een heel belangrijke oriëntatiepunt. (...) dat geeft mij een beeld van hoe afstanden zich verhouden. (...) Ik zie eerst de muren, zal ik maar zeggen.

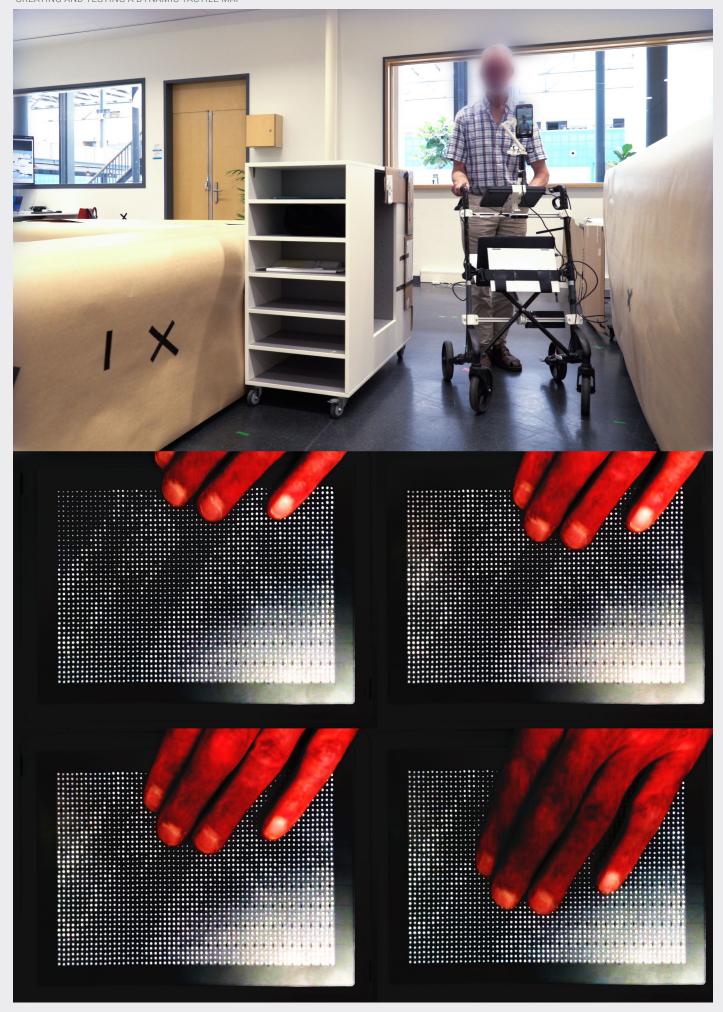


Figure 5.8 It can be seen how the participant scans the space ahead

LIMITED DETAIL AND RICHNESS OF ENVIRONMENTAL DISPLAY

The prototype only provided participants with a very abstract representation of the environment, which does not allow them to recongize and differentiate between different elements of the environment. The recognition of the environment is crucial for understanding the space, landmarks for self-orientation and recognizing your goal.

P3 explains something similar: "Finding my end goal is difficult. I initially thought that I had to go forward and a little bit to the right, and then the door should left of me. I assume this is the wall, but I can't check that."

P4 explains how the ability to recognize the environment could lead to better navigation: "Wayfinding becomes difficult when you have to find a specific point. And that's where you have to start guiding people extra. A nice thing about this technology would be if you could indicate those kinds of things. That would be a real improvement."

It is observed among the participants that when they were asked to 'explore' the space, they lacked the incentive to explore certain parts of the space, because the binary display turned everything into an equal 'obstacle': A more vivid environmental perception could provide more stimuli to become curious and engage with the environment.

P2 explains that he is not able to recognize the environment, but that he would want to know what it is that he is seeing: "Op dit scherm krijg je alleen maar: 'er is iets'. Ja,en vaak wil je toch ook wel weten wat er is. En soms ook niet maar ja, in je beleving ik denk je heel vaak wel wil weten wat er ongeveer is omdat ja, ook met je oren kan je verschil horen tussen gras, struiken en een muur."

FREE MOVEMENT THROUGH SPACE WITH THE MAP

Participants showed that they were able to dynamically orient themselves based on their perception of movement of the environment, without using physical guidelines. This allowed them to make spatial decisions based on the map such as determine that they arrived at a turning point, make accurate rotations based on far away heading 'references' and allowing them to traverse open space without needing a guide line up close (the whole space around became their 'guide line').

P4 explains the potential for effective orientation in open spaces: "Nothing's harder than knowing where you are, for example on a soccer field, when you can't see the edges, because you have no idea where you are then. With this system you can do that: I can feel if I'm on the center spot or not. And if you don't have that visual reference it's impossible. It's really about relationships: where you are in a space, where you are in relation to other things, in relation to a door."

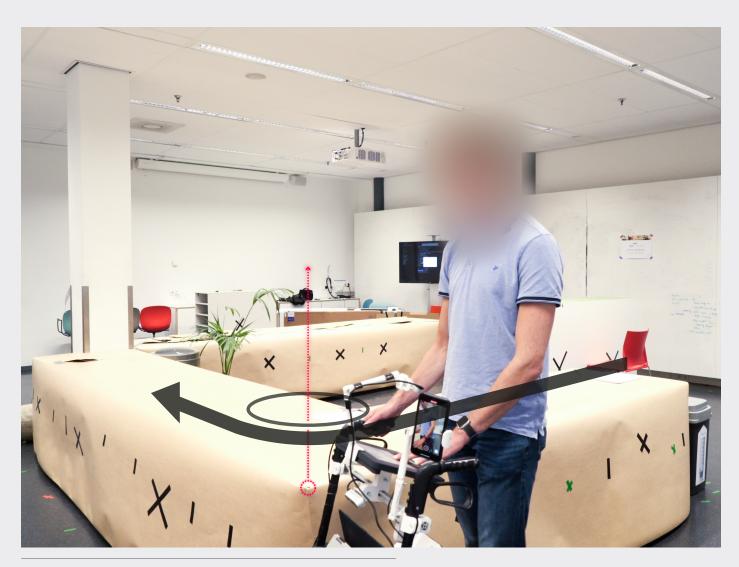


Figure 5.9 Rotating around a turning point felt in the map, a virtual guideline

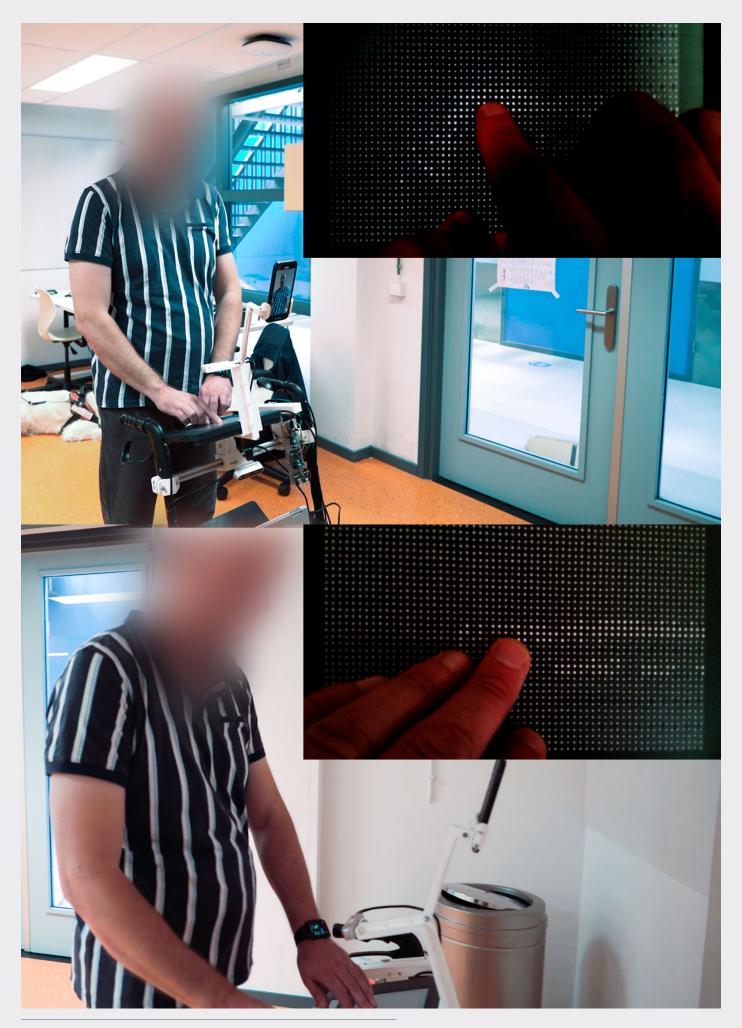


Figure 5.10 Tracking a corner of the room and the wall in front to decide when to turn right



Figure 5.11 A participant anticipating a wall and turn coming up

OVERVIEW AND PREVIEW IN THE PATH

The prototype shows the potential to **reduce** the alertness required during movement due to the newfound overview and preview in the path and the ability to anticipate obstacles up ahead.

P3 explains: "You need to be less taken up with scanning the environment in front of you, because your range that perceive is greater, so you can see things coming from further away. Now this is sometimes difficult because of that refresh rate, but I believe when you get that higher, you can see things coming much earlier, whereas with your stick you don't see them coming until you run into them."

However, the prototype's inability to refresh underneath the fingers and its low refresh rate inhibited the direct perception of movement in the map, which required the VIP to wait and make deliberate comparisons between updates the map. This makes the process of perceiving movement require more energy and mental effort, limited the ability to move with the environment and to maintain overview and anticipate obstacles during movement.

P4 describes that he needs to be able to perceive real-time movement and the ability to recognize the environment for the DTM to be truly useful for wayfinding: "The device does indeed give an overview of the space. And yes, in concept that certainly helps to navigate. In practice, it is complicated because, of course, it does not always track real time in all the details yet. (...) But if this would track real time, then I can certainly use this to safely pilot through space later and also get to a destination."

COGNITIVE CHALLENGE FROM TRANSLATING MAP TO REAL WORLD

Translating map space to real-world space was challenging, and articipants often found it confusing to translate map directions into real-world ones and understand real-world distances.

P1: "It is a little difficult to estimate how narrow is this path in reality because you have to interpret the scale. This is is always a bit of estimation. If you stand there touching or hearing how wide it is, then you can understand how wide you can walk."

P1 explains that he would have expected the destination to be in a different location based on its location in the map, however, in this situation, the prototype was rotated in relationship to his body: "Based on the map, to my mind, the destination would be there. Whereas based on the music, it must be over there."

DEDUCING DISTANCE FROM MOVEMENT

To ensure intuitive map reading and the formation of a comprehensive, constant overview of the environment while moving around, this mental translation must be made easier. Interestingly, participants were able to deduct the map's scale by comparing

movement of the environment with their actual movement, however this was still difficult due to the inability to easily and accurately perceive movement in the map:

P7: "The last time, the scale was 8 centimeters, now it's 4. Now we've turned, and now I now have a piece here of maybe 3 or 2 centimeters. So I think I have to move forward 1 or 2 meters, and then I can turn to the right."

Understanding environmental movement and rotation in response to their own actions was confusing for users, particularly for those who are congenitally blind and unaccustomed to such perceptions. Similarly, frame movement caused by zooming also felt confusing.

P2 - "What is zooming in and what is zooming out? In my opinion, you make the free path larger, so to speak. You see, I have to think about it. I had the experience that the wall moved away from me and became smaller. That is my association, while in reality, of course, that wall has not changed. However, the details have become larger."

Another difficulty is that participants occasionally lost their place on the map while exploring it with their fingers, leading to difficulties in relocating their own position marker.

5.3 CONCLUSIONS

Experimentation with the DTM prototype yields critical insights into its potential and areas of improvement, which will serve in guiding the design of an advanced DTM. The findings from the building phase and the experiment lead to implications for a more advanced version of the DTM concept. The experiment reveals that the concept helps users form a detailed mental image of their surroundings, including layout, routes, obstacles, and landmarks. The

prototype allowed participants to coordinate their movement based on movement of the larger environment and allowed for real-time orientation, anticipating paths and avoiding obstacles by using the map to view the space ahead, although these processes were significantly hindered by the low refresh rate. The resulting strategies are described below, and key areas of improvement are described in the next section, design implications.

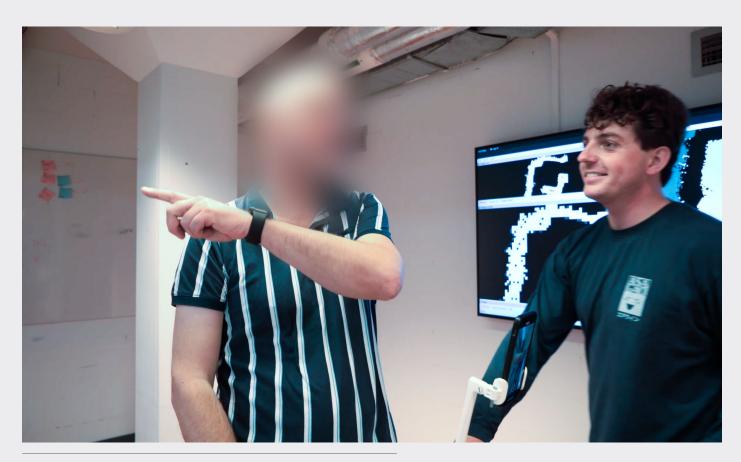


Figure 5.12 "The start of the route must be somewhere over there"

STRATEGIES FOR ENHANCED MOBILITY

The development and testing of the DTM prototype revealed a new approach to mobility for VIPs that a dynamic environmental overview promises to enable. These strategies were still in its early phase, because of the low detail of the map of the prototype and the low refresh rate, but clear signs of this new mode of mobility were observed in the experiments. These topics were introduced in the previous section, but the strategies are clarified here, as they are very important and underpin the design of a more advanced, future DTM.

DYNAMIC PLANNING

The DTM enabled participants to overview their surroundings from afar, forming a mental map that led to broader spatial awareness. This is a pivotal aspect of the DTM's utility, shifting the focus from near-field perception to a broader spatial awareness. It enabled them to consider different routes through the environment and choose the most efficient or otherwise preferred routes. When the environment changes, the VIP can flexibly respond by reconsidering their route.

OVERVIEWING AND EXPLORING WHILE MOVING

One of the most significant advantages of the DTM is the ability to establish broader environmental awareness while moving. Extended perceptual range allows them to 'see' beyond their immediate vicinity, enabling a proactive movement strategy, transitioning from merely avoiding obstacles to actively exploring their environment.

MOVING WITH THE MAP

The ability to perceive real-time movement on the map and translate it into spatial decisions promises to be a game-changer in VIPs' navigational strategies that enables movement free from the guideline: the distant environment becomes their guideline. By correlating physical movement with the dynamic changes on the map enables an understanding how far one has moved or turned, or how far they still have to move or turn. This enables users to anticipate upcoming obstacles or changes in the environment, allowing for smoother and more confident navigation.

SCANNING AHEAD

The DTM enables a shift from a reactive approach (responding to immediate obstacles) to a proactive one, planning movements well in advance. During movement, users scan their environment ahead, foreseeing upcoming space, obstacles and hazards and planning their movements in advance. This proactive approach marks a substantial shift from the reactive strategy typically used with a cane, enhancing their ability to navigate confidently and efficiently.

DESIGN IMPLICATIONS

The experiment revealed several areas for improvement:

- The interface needs major enhancements for a richer environmental perception.
 The current binary display is too limited, lacking detail and depth. A more vivid, high-resolution interface that allows for recognition and distinguishing between environmental elements would help users better understand, navigate and explore the environment. However, the risk of sensory overload should be managed by balancing information across senses and selecting relevant data.
 - a. Higher detail in the map is needed to bridge mental scales: The map's limited resolution enabled a narrow scale spectrum per zoom level. There is a need for maps with greater precision without compromising the bigger picture.
 - b. The map requires higher resolution to effectively bridge mental scales. Its current limited resolution restricts the spectrum of scales at each zoom level. To improve movement accuracy without losing the overall context, the interface should offer a more detailed map. However, considering finger sensitivity limitations, zoom functionality is crucial. It must be finely tuned to align with users' mental process of scaling and understanding space.

- 2. Direct, precise perception of movement required
 - a. A future version should offer real-time, accurate movement feedback. This would aid in maintaining overview and orientation during movement, more precise orientation and understanding of map scale and reduce the vigilance, facilitate exploration, and potentially alter traditional walking strategies.

- 3. Better map to world translation required for intuitive environmental perception
 - a. A more direct perception of map scale, such as through a reference of one's own size within the map is required for accurate movement and environmental understanding.
 - A better mechanism to maintain continuous awareness of heading and one's position on the map is a key area for development that would result in easier movement and orientation.
 - A mechanism that ensures a clear mental mapping of the map's front and the user's body is important to avoid confusion.
 - d. The map's reverse movement and the impact of zooming were difficult to understand at times. Further research is required to understand how VIPs adapt to these phenomena. This becomes a topic for future research.

- 4. Improved environmental mapping and selforientation technology
 - a. A more reliable self-orientation system is required. This requires an improved field-of-view and a fused sensor system.
 - A future device needs to be able to map space at a much higher range, at a higher pace, to enable the user to explore unknown environments without needing to deal with too much unknown space.
 - Sensors for environmental mapping must be able to function reliably in daylight situations.
 - d. The device will require a dedicated chip for the self-localization and mapping algorithms and processing of sensor feeds to effectively and efficiently perform computation.

6 CREATING AND TESTING A MAP WITH INTENT

"Imagine products we are familiar with, such as lamps, jackets, and toys. Now imagine they are given a purpose: The lamp wants you to have a good night's sleep; the allow designers to focus on the jacket encourages you to calm expressiveness and interactivity of down; and toys wish for you to be active. I call these artifacts

Objects with Intent" (Rozendaal et al., 2019)

This chapter explores the Object with Intent (OWI) concept and its application in assistive technology for the mobility of VIPs. It establishes a theoretical background that highlights the OWI's unique attributes as interactive, intelligent partners integrated into users' daily lives. The focus is on how OWI's, through intuitive design, address VIPs' emotional needs in moibilty, targeting feelings of fear and lack of control and the resulting reduction of enviornmental engagement. Specific roles of OWI in VIP mobility are

examined, including enhancing environmental awareness, encouraging exploration, and serving as a learning aid, ultimately aiming to transform assistive technology from mere functionality to empowerment.

The process begins by explaining the OWI concept. Following this, it details a research-through-design approach focused on developing a collaborative framework between the assistive technology and the user, achieved through experimental exploration.

6.1 THEORETICAL BACKGROUND

The Object with Intent (OWI) represents a novel paradigm in the design of human-agent collaboration, an area increasingly relevant in the realm of assistive technologies. OWI's are distinguished from conventional smart devices by their unique integration into the everyday life of the user. An OWI leverages familiar forms (e.g. by mimicking the appearance of familiar, everyday items) to intuitively embed advanced functionalities.

"For example, consider a lamp that wants you to have a good night's sleep by automatically dimming the light as the evening progresses to make you sleepy. Additionally, the lamp makes it more difficult for you to increase the

brightness of the light. The longer bedtime is postponed, the more assertive the lamp becomes in its behavior" (Rozendaal et al., 2019)

In the context of assistive technology for the visually impaired, an OWI transcends the role of a mere tool, evolving into an intelligent partner that actively collaborates with its user. It is designed to be perceived more as an object than a human-like entity, thus ensuring immediate familiarity and intuitive interaction. This design philosophy is crucial in creating assistive technologies that are not only functional but also seamlessly integrated into the user's daily life.



Figure 6.1 Impression of the Lamp with Intent

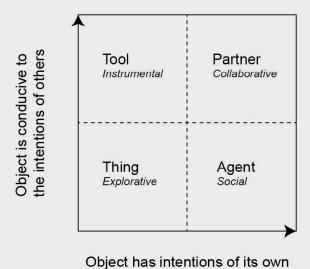
THE TOOL-AGENT SPECTRUM

Central to understanding OWI's is the toolagent spectrum, seen in the image by Rozendaal (2019) in figure 6.2 below. The spectrum describes how an OWI can be perceived differently based on its role and context – as a tool when it primarily mediates the user's intentions, and as an agent when it acts based on its own intentions or in a blended manner. This fluidity allows the OWI to adapt to varying situations, leaving the user to their task and sometimes intervening. This is particularly relevant for the dynamic context mobility for VIPs.

DIRECT, EMBODIED INTERACTION

Interaction with an OWI is characterized by its directness and embodiment. Actions of the OWI are directly linked to an action of the user, as opposed to a symbolic or semantic interaction, where actions can be meant to simply convey information (as is the case with conversational agents like ChatGPT).

Interaction with an OWI aligns with Dourish's concept of 'embodied interactions', that emphasises the significant role of physical context in shaping interactions. Direct interaction with an OWI involves tangible, real-time responses to user actions, moving beyond symbolic or abstract engagements like typing commands or speaking to digital assistants. It's about physical involvement – for example, squeezing, tapping, or tilting the OWI, and receiving intuitive, immediate feedback related to these actions.



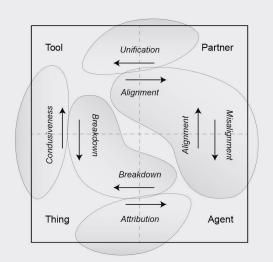


Figure 6.2 The Tool-Agent spectrum and visualisation of shifts along the spectrum

Designing the embodied interactions for the conceptual product therefore requires to think about the broader experience of the user. The goal is to create a device that feels like a natural extension of the user's body and fits seamlessly into their world, enhancing their ability to navigate and interact with their environment in a way that feels intuitive and creates a certain 'flow'.

COLLABORATIVE DYNAMICS AND AGENCY

Interaction between a (human) user and an OWI takes the form of a collaboration, where both the user and the OWI are autonomous and have their own goals and agency. The OWI can take up different roles in the collaboration. Within these roles, the OWI has different intentions towards its user. The OWI, capable of assuming various roles, must align its intentions with those of the user. This dynamic necessitates a nuanced design approach where the shifting roles and responsibilities are carefully considered, ensuring a harmonious partnership.

A key element in this interplay is the negotiation process, particularly when intentions conflict. For example, a mobility aid might caution against crossing a street due to oncoming traffic, despite the user's desire to cross.

Such scenarios require a delicate balance of trust, where users understand when to rely on the OWI's judgment and when to override it. It can safely be assumed that mistakes will be made during the collaboration by both partners. It is important to calibrate trust: Users need to understand when they can trust the OWI's decisions and when they need to override or ignore them. Similarly, the OWI should be able to understand when the user makes a faulty (or potentially dangerous) decision and more strongly intervene, especially in hazardous situations.

Therefore, when designing the OWI, it's important to consider the partnership's dynamics: How are roles divided between the human and the OWI? How are intentions communicated and negotiated? How is trust established and maintained?

AN OWI FOR MOBILITY OF VIPS

With the theoretical background set, this the relevance and potential of the OWI in enhancing the mobility experience of VIPs can be explored, focusing on its unique ability to address emotional needs and foster a sense of control and confidence.

A primary design objective of the OWI in this context is to alleviate feelings of fear, vigilance, and the perceived lack of control that VIPs often experience. These emotions are largely attributed to the challenges in environmental awareness and navigation.

Through its design as a collaborative partner and can actively participate in the process that establishes a streamlined collaboration and establishment of calibrated trust, the device as an OWI may spark a sense of familiarity and bonding. This connection between the user and the OWI makes it especially well-suited

as a buddy during travel, that for example collaborates in and watches along during the process of mobility. The familiarity can be beneficial in mitigating fear experienced during the process.

Furthermore, the OWI is, by nature, designed to be intuitive and familiar. Its interaction is supposed to be direct and intuitively linked to user actions and, if designed well, achieves a certain 'flow'. It therefore has great potential for aiding in the mobility process while reducing the cognitive load and for example helping in the increase of spatial awareness without the user needing to put much effort into obtaining extra information via the device.

Following a thorough ideation process, various potential roles for the OWI have been envisioned, the details of which are provided in Appendix I. The most relevant roles for the OWI that this resulted in are described here:

The following section will discuss the experimental process with these different roles and the development of a collaborative framework for the final design.

ENHANCING ENVIRONMENTAL OVERVIEW AND REDUCING VIGILANCE

The OWI can act as a watchful companion, subtly alerting users to potential dangers through intuitive signals, thereby enhancing their environmental overview in an intuitive manner without them needing to actively to tend to it. This support can decrease their sense of vulnerability and boost confidence in navigating various settings.

COLLABORATIVE EXPLORATION AND EXPERIENCE

The OWI can facilitate exploration and interaction with the environment. It can suggest safe yet unfamiliar routes, encouraging exploration and enriching the user's environmental experience with contextual information, thereby helping turn the mobility process into a more informative and engaging experience.

THE OWI AS A LEARNING BUDDY OR MENTOR

The OWI can actively partake in the learning process associated to the use of this novel assistive technology in the form of the 'map that teaches itself'. It could for example help in their understanding of the map or draw users' attention to overlooked aspects. Or it might act as a mentor that guides the gamified learning experience, as described earlier in the report.

6.2 DESIGN THROUGH EXPERIMENTATION

This research aims to explore and develop the Object with Intent (OWI) as a collaborative partner in mobility process of VIPs. It seeks to enhance the mobility experience beyond mere functionality, focusing on a confident feeling of overview, engagement and interaction with the environment. The experiments consist of in-context sessions with VIPs, using a mix of wizard-of-oz enactments and Ultra-Rapid-Prototyping. This method enables the exploration of several pre-devined roles and interactions, but leaves room for unexpected outcomes.

The study leads to a conceptual design where the OWI interacts with users through a **physical push-pull language**, that provides them with an intuitive extra sense that leads them them away from hazards, bearing similarities of an interaction with a guide dog. This interaction, an addition to the environmental awareness provided by the DTM, emerges as a unique communicative 'language'. It becomes an additional sensory experience for participants, enriching their environmental perception.

For the conceptual design, the focus will be on this push-pull interaction, but the OWI's potential roles in this context are vast and open for future exploration. For detailed information on the design and experimental process, see Appendix I.



Figure 6.3 In-context explorative research

DESIGN & ROLES

During the experiment, the prototype was not fully functional due to the unavailability of the DotPad, limiting the exploration of the Object with Intent (OWI) through the map. Attempts to mimic the Dynamic Tactile Map's (DTM) effects with basic tools failed to effectively replicate the desired impact for participants. This limitation shifted the focus of the research to study the embodied interaction independent of the DTM, as integrating the OWI with the DTM could not be examined.

Two primary roles for the OWI were explored: the Curious, Explorative Partner that focuses on enhancing environmental engagement, and the Observant Partner that intends to keep the user away from dangers. The following two directions for the object with intent are explored:

THE CURIOUS, EXPLORATIVE PARTNER

This role aimed to enhance the user's engagement with their environment. The OWI acted as an active participant, suggesting routes, highlighting points of interest, and encouraging exploration. However, its effectiveness was limited by the current prototype's inability to provide detailed spatial information.

THE OBSERVANT PARTNER

In this role, the OWI acted as a watchful partner, alerting users to obstacles and dangers, steering them away from hazards, and guiding them along safe paths. It used varying intensities of force to communicate safety information, effectively reducing the need for constant vigilance by the user.



Figure 6.4 The envisioned assistive technology sometimes acts solely based on user's intention, and sometimes on its own

FRAMEWORK FOR COLLABORATION

The research yields a physical push-pull language between the user and OWI, which enhances environmental perception and interaction.

The research yields a clear direction for the interaction mechanism between the user and the OWI in the design for the future concept:

- The user and OWI partner up in the process of moving through environment and collaborate through an embodied push-pull language that (based on the principle that physical forces) can effectively negotiate navigational intentions of each of the collaborative partners.
- Pull Forward for Faster Movement: A
 forward pull suggests that the path ahead
 is clear, signaling the user can move faster.
 The cessation of this pull indicates a return
 to normal walking speed is appropriate.
- Opposing Force for Caution: An opposing force, or push, indicates the need to slow down and heighten awareness, often used in situations like approaching narrow spaces or obstacles.

- Increasing Force for Nearing/Imminent
 Hazards: An intensifying force while moving
 in a certain direction serves as a strong
 indication that proceeding in that direction
 is unsafe, likely due to an imminent hazard.
- Sideways Force for Directional Adjustment:
 A force applied sideways suggests a need to change direction, guiding the user to steer left or right.
- 6. Negotiation Pushing Back to Signal Disagreement: When a user pushes back against the OWI, it signals their different intention or desire to proceed despite the warning. The OWI can then decide if this decision by the user would not lead to real danger and potentially stop pushing.
- 7. Tempo Regulation: The OWI can change how hard it pushes or pulls to control the user's speed based on the environment. In tight or tricky areas, it slows the user down by pushing back. In open areas, it speeds up by pulling forward. This is like how guide dogs change their walking speed to suit their surroundings

6.3 CONCLUSIONS

The explorative research results is a collaborative framework that will be incorporated in the future concept of the DTM in which the intelligent assistive device partners with the user in environmental exploration and mobility, shifting between a passive perceptive tool and an active external partner has the intention to hint the user at potential hazards and, when needed, keep them away from it.

The device communicates with the user through an embodied push-pull language that promised to be an intuitive and direct method of communication between the device and the user, enhancing the intuitive perception and exploration the environment. The concept should incorporate a feasible technology for implementing force feedback that allows for the following embodied push-pull language.

However, the research was constrained by the unavailability of the DotPad, limiting the exploration of the OWI's integration with the Dynamic Tactile Map (DTM). The need for integration with the DTM was evident, as spatial information is crucial for effective environmental interaction and exploration.

Therefore, the recommendation is made that future research should be conducted that focuses on:

- Integrating the OWI with Dynamic Tactile Map to enhance spatial awareness and encourage exploration.
- Refining the push-pull Language through further in-context testing to offer more nuanced and context-specific feedback.
- Exploring additional roles, such as an educative partner or a partner in environmental exploration.
- Transparent Decision-Making: The concept of trust-calibration was not considered in the research. In further research, efforts must be made to ensure the OWI's decision-making process is transparent and establishes trust and understanding between the user and the device.

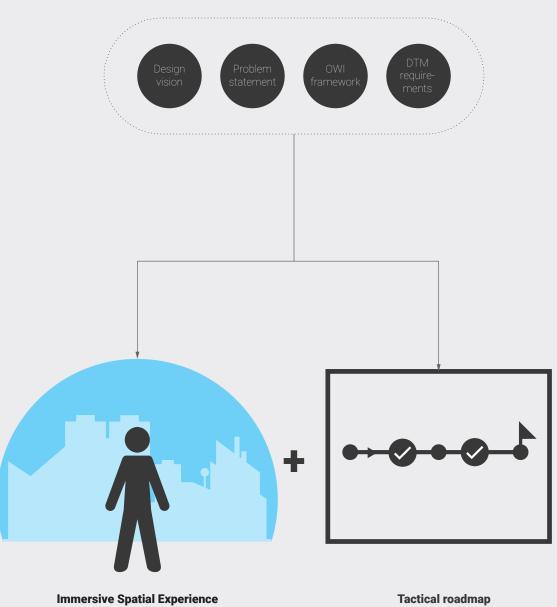
FUTURE VISION

The final design phase integrates the project vision, insights in the target group and Mobility of VIPs, technology, OWI, and the concept of the DTM into a cohesive conceptual design.

The outcome of this integration is the Immersive Spatial Experience (ISE), an innovative yet realistic conceptual assistive technology that embodies the project's future vision for Mobility of VIPs. This concept is grounded in the research conducted on design and technology. For a full overview of the starting points, design implications and requirements, see Appendix J.

An important aspect of this phase is balancing ambitious long-term goals with achievability, which is vital for gaining market confidence and investor interest, ensuring the concept's achievability and credibility. Therefore, a roadmap is developed to guide and support the development process of the conceptual product. This roadmap details and communicates the process of development of the value proposition, product interaction, and embodiment over time, considering technological advancements, design research, and interim product stages.

First, the chapter presents the conceptual design of the concept of ISE and ends with the roadmap and technological substantiation of the concept.



Future Concept Vision

7 IMMERSIVE SPATIAL EXPERIENCE (ISE)

ISE is a conceptual technology designed to enhance the mobility of people with a vision impairment through a comprehensive environmental awareness.

ISE harnesses the power of haptic augmented reality to bring an intuitive 360° perception and a fuller understanding of their surroundings that is accessible at any time.

The dynamic spatial awareness empowers them to navigate and move with a wider perspective of their surroundings, independent of traditional guidelines, while confidently maintaining an overview of and anticipating obstacles and hazards. The detailed and immersive perception of the environment, aiding users in comprehending and learning about their surroundings as they traverse through them.

Through enhanced environmental awareness, ISE users can mind the broader environment while moving, rather than solely on safety and wayfinding. This shift in focus enables engagement with the world and encourages exploration of new areas with increased confidence and enjoyment. ISE allows users to broaden their horizon and grow their living world and participate in society will full freedom.

ISE's approach to spatial perception builds upon the DTM prototype's groundwork, which successfully used a 2D haptic screen to enable dynamic environmental perception for VIPs. This chapter outlines the design of the ISE, explaining how it evolves from the prototype.

The hologram images serve as conceptual illustrations of a haptic AR map, representing how it might be perceived by a VIP. It's important to note that these are not real holograms. In reality, VI users experience this haptic 'hologram' solely through touch, feeling it only where their hands contact the device.

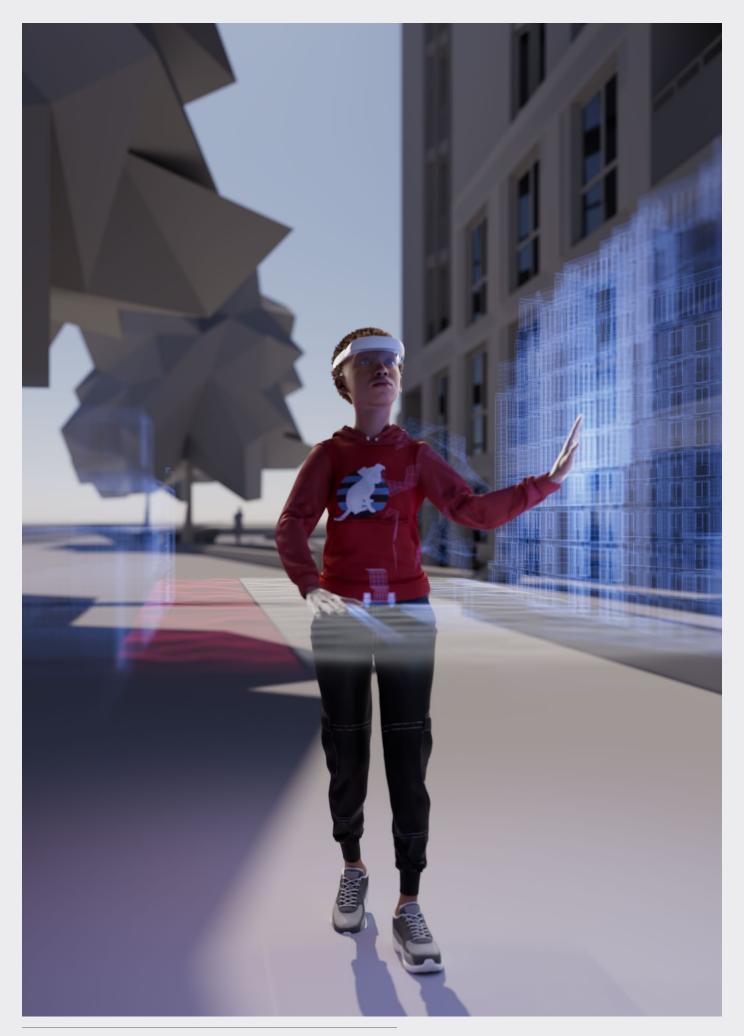


Figure 7.1 Immersive Spatial Experience

7.1 HARDWARE

At the heart of ISE lay 2 important components:

- Augmented Reality Glasses scan the environment and transform it into a dynamic 3D map. These glasses also monitor hand movements to facilitate haptic feedback. The decision to use
- 2. Haptic Gloves are employed to deliver tactile sensations that vary based on the fingers' position. This interface allows users to sense 3D geometry through force exerted on their fingers, augmented by haptic textures and surface temperature simulations, which offer a realistic experience of different materials. Consequently, users can experience a virtual, dynamic 3D representation of the world around them.
- The choice of a mainstream technology for environmental mapping

Applying mainstream AR glasses potentially reduces technological overlap, but also a custom mapping technology could be developed. This consideration is further discussed in in the Tactical roadmap section.

Feasibility of the haptic interface

The haptic AR interface, while currently still speculative, builds on swiftly advancing existing technologies, primarily evolving in the gaming and mixed-reality sectors for industrial use. Several products currently on the market are progressing towards realizing this vision, as discussed in the Tactical roadmap section.

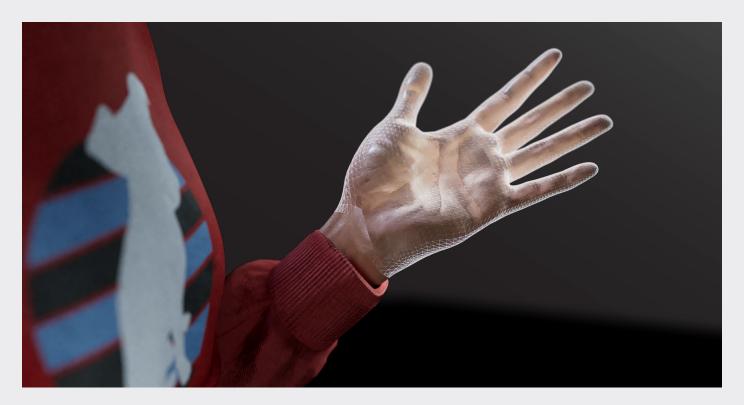


Figure 7.2 Conceptualization of the haptic gloves

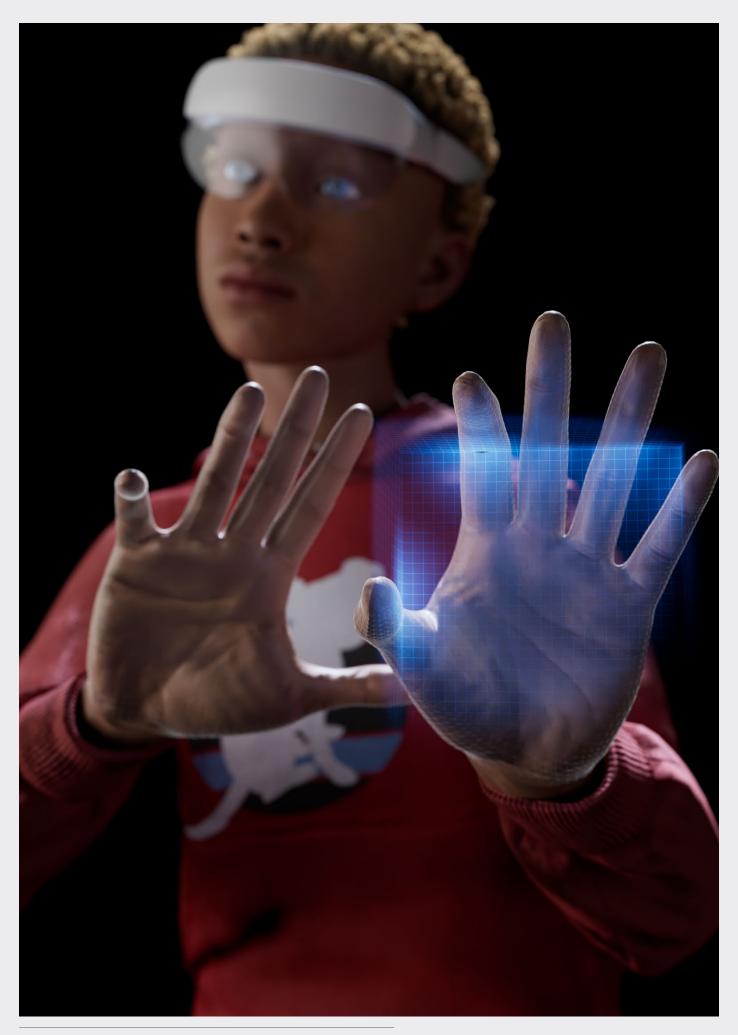


Figure 7.3 The haptic interface, AR glasses and 3D geometry

7.2 ENVIRONMENTAL PERCEPTION WITH ISE

The user feels a virtual, dynamic 3D map (a scaled version) of the world, in 360° around them. They view the world through the map's three-dimensional geometry, that displays the spatial layout of their surroundings, and moving elements within it such as other traffic participants.

As they move around, the map moves along with them; elements in the map are perceived in the same direction as their physical counterparts in the real world. As the user moves around through new environments, ISE maps this new space, making these areas accessible for future reference and to other users as well.

Why Haptic AR?

Haptic AR enhances immersion by merging digital and physical realms. Unlike screen-based interactions that divert attention, AR allows users to engage with their environment directly. A 360° AR map offers a realistic sense of direction and movement, keeping users connected to their surroundings. This approach significantly surpasses traditional screen use, aligning well with the project's aim for an immersive environmental experience.

Benefits and difficulties of the 3D environmental perception

ISE's 3D geometry offers a more detailed environmental view compared to the prototype's 2D representation, including object heights and shapes. However, mastering this 3D perception may require user training. To simplify this process, complex shapes could be abstracted into more recognizable forms. Thus, designing the optimal environmental representation requires careful consideration and future research.

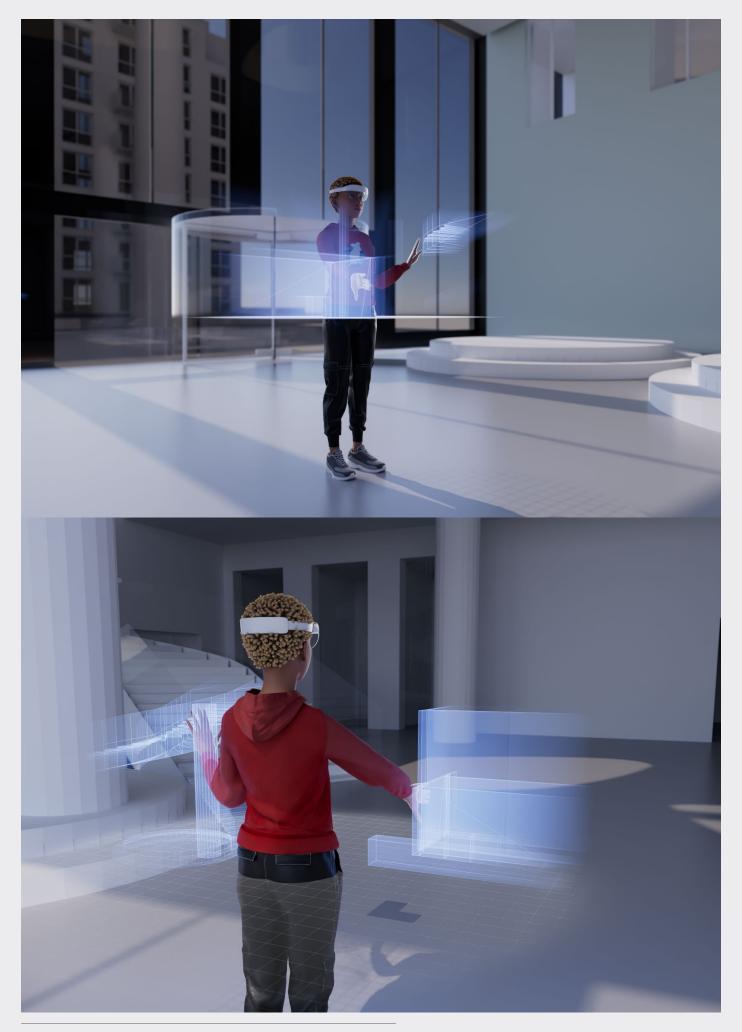


Figure 7.4 360° map and field of perception

INTERACTIONS WITH THE 3D MAP

Users can zoom, move and interact with elements in the map through physical interactions with the 3D geometry.

Users can manually adjust the map's scale to look at the world in more detail or to gain a broader overview, zoom in on specific areas or out towards a larger perspective and moving it for detailed examination of specific areas.

A pinch gesture activates a scale reference marker that offers a sense of their own size within the environment, to enable an understanding of the current map's scale.

At very high zoom levels, the map shows a broader view of larger environments like cities, focusing on the spatial structure rather than small-scale dynamics, similar to a 3D world view on a global map application.

By tapping elements in the map, they obtain an auditive description and additional information about this map element.

Standard Scale & Scale reference marker

The map's standard scale offers a balance between an overall view and detailed perspective, automatically zooming in while moving for precise orientation and zooming out when stationary for a wider view.

With the prototype, participants showed that they were able to deduce the environment's size from the size of a object on the map with a known physical size. The scale reference marker is a direct translation of this, and the scaling reference that was often mentioned by participants in the experiment.

In the experiments with the prototype, participants showed that they were able to understand map scale after some getting-used-to. Changing the scale too often frustrated this understanding and required the user to reassess the scale. Therefore, the standard scale allows the user to intuitively understand scale.



Figure 7.5 Interactions with the map

MULTISENSORY PERCEPTION

Perception of the world through the 3D map is enhanced with a sense of materiality through haptic textures and temperature simulations, along with audio cues through AR glasses

Haptic textures and temperature simulations offer a tangible sense of materiality, crucial for distinguishing between different objects. For instance, the coolness of a metal railing as opposed to the warmth of a wooden bench provides an intuitive way to identify these materials.

The ground surface is detailed with haptic textures and relief to provide extra information. For example, Natural surfaces like grass are represented as softer and smoother, contrasting with the rougher texture of concrete or other man-made surfaces. Areas that are potentially dangerous or non-walkable, such as roads, are marked with a distinctly aggressive 'warning texture' that helps users recognize and avoid these spaces.

Auditory textures add another dimension to the map. Ambient sounds associated with specific environmental elements provide a subconscious stream of information. For example, the presence of a water body is indicated by the sound of water.

Not all environmental details can be effectively conveyed through shapes or textures. Here, auditory descriptions become invaluable. By tapping on an element, users can receive spoken information about it. In an urban setting, this feature could allow users to hear names and details about buildings as they walk past them, enriching their understanding of their surroundings.

This multisensory perception of the world in 360° around the user creates an immersive and comprehensive understanding of their environment.

Feasibility of material expression through AR interface technology

The feasibility of expressing material properties through AR interface technology is already a feature in existing AR products and is the topic of widespread ongoing research, as highlighted in section 9.2 of the Technological Substantiation.

Avoiding sensory overload

While the addition of multisensory information enriches the map, it is crucial to avoid overwhelming the tactile sense. A more vivid representation of the world is achievable through the inclusion of multiple senses, but care must be taken not to bombard users with excessive stimuli, such as auditory textures. The integration of information in the map should be carefully tested and designed.

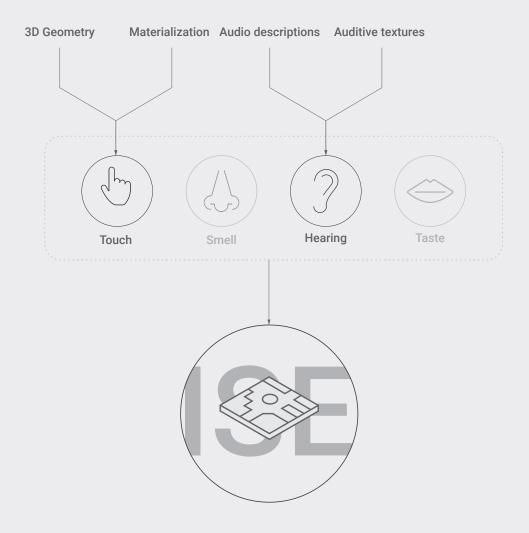


Figure 7.6 The different components of ISE's multisensory perception

7.3 MOVING WITH THE ENVIRONMENT

Perception of movement in the map enables the user to use moving map elements as reference for their own motion and orientation.

SCANNING AROUND

While moving, the user scans the environment in front of them, to perceive anything is in their way that requires a change of course.

Upon movement, the map zooms in to a detail level that enables for accurate movement while retaining a sense of environmental overview.

TRACKING MOTION

Similar to the prototype, through tracking elements in the environment as they move, say, for example, a corner in the path ahead or a wall, they perceive this element nearing, eventually perceiving that they need to turn. Continuously tracking environmental elements in this way allows for controlled movement through the environment based on the broader perspective, rather than the environment within reach. Tracking environmental elements is also used for maintaining heading. By tracking or locating for example one's destination in the map, they understand how they are oriented in relation to it.

Research requirement of map scanning in crowded environments

The process of reading the map requires continuous scanning and tracking, often amidst other pedestrians. This raises a concern about users accidently making physical contact with others. One potential solution could be to decrease the map size in tight spaces, but this needs experimental validation. Additionally, this kind of 'groping around' behavior might result in users feeling self-conscious or embarrassed, potentially deterring them from using the product. Monitoring and addressing this psychological aspect is crucial in the further development of the concept.

Motion perception in the AR map and research requirement

The concept of using map motion for own movement is validated in the experiment using the DTM prototype. However, in 3D, this experience will inherently be different. The experience is heavily dependent on the interface technology, particularly in how it represents physical geometry. For example, whether a user feels a wall through force or merely as a tactile sensation, allowing their hand to 'pass through' it, alters the experience. Future research with advanced technology should explore how users perceive approaching elements and environmental movement in a 3D space.

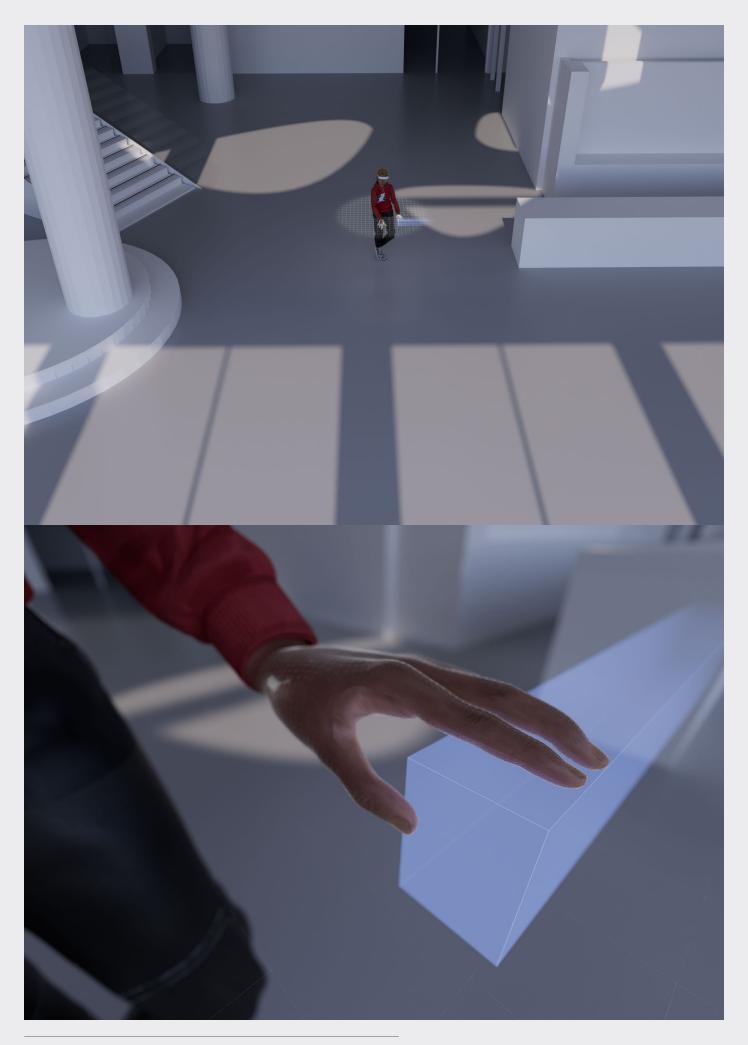


Figure 7.7 Moving with the map in 3D

7.4 ACTIVE PARTICIPATION

To assist in the dynamic and sometimes hectic process of moving through public space, ISE actively collaborates by watching along with the user and warning of potential hazard through an intuitive 'push' in its direction applied by the haptic gloves, essentially creating an extra, intuitive environmental sense.

Moving obstacles and hazards require extra attention. To signal the proximity and velocity of such elements, like a fast-approaching person or a suddenly opening door, ISE dynamically scales its map and applies a force on the hand, as a warning signal directed towards the element needing attention, like a 'push' by the map, to highlight this source of potential hazard and allow the user to act on in real-time.

The intensity of the sensation varies based on the type of moving obstacles. For example, the approach of a vehicle might trigger a more urgent push, while a slowly moving obstacle like a pedestrian creates only a slight force. This also helps perceive small elements, which might be missed in dynamic situations but may form a potential hazard. This allows the user to make quick, informed decisions about when to pause, step aside, or proceed with caution in response to unexpected changes in their surroundings. Upon perception of such a signal the user can then zoom in to identify the cause. This direct mapping is expected to become a subconscious perception over time. The directional, physical feedback enables intuitive perception of nearby elements of interest without the need for exhaustive scrutinizing of the map.

Depending on the user's preference, ISE may actively guide users away from hazards and towards safer paths, akin to the guidance provided by a guide dog.

Extension of ISE as an Object with Intent

There are many more roles imagineable for ISE to actively collaborate, such as participating in environmental exploration process, or as a 'learning buddy' in the process of learning to work with ISE. This will be further discussed in the future recommendations.

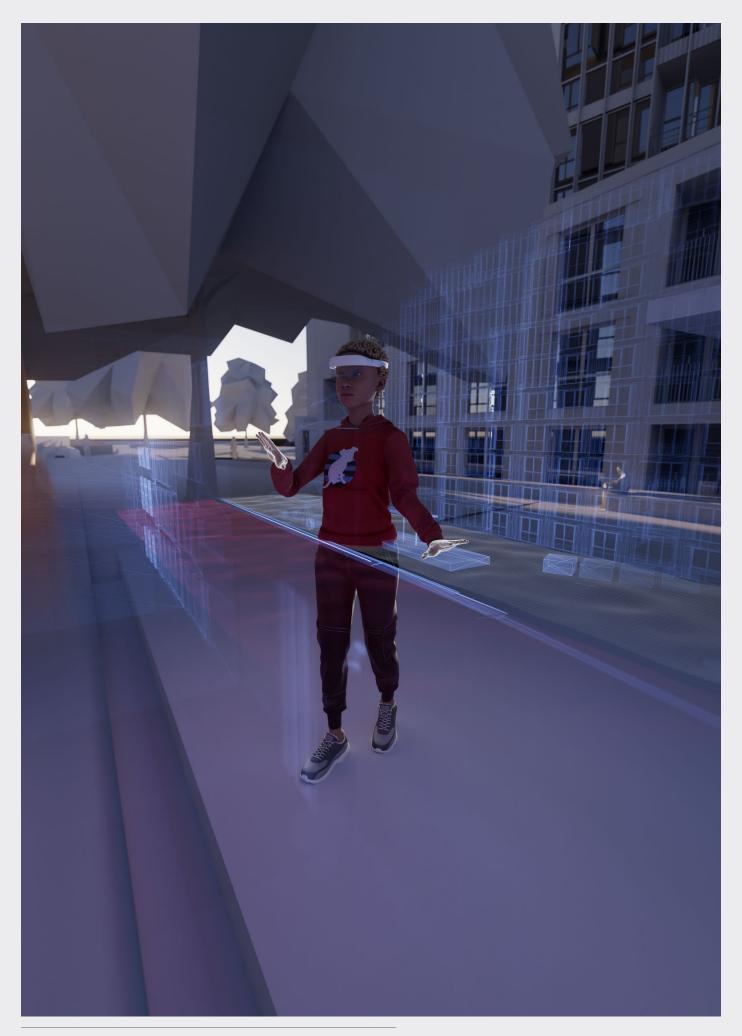


Figure 7. ISE provides the necessary feedback to avoid the user moving into dangerous zones

8 TACTICAL ROADMAP

This chapter outlines the future development process of the concept of the dynamic tactile map, with the ISE concept as its furthest point on the horizon. The roadmap, shown in figure 8.2 on the next page, is designed to support and present the development process. It shows the development of the product and its the value proposition as a function of time, technological research and human-centered, and describes and substantiates technological decisions.

This roadmap should be seen as a dynamic document, intended to spark conversations within the development team, among all

stakeholders, and technology experts. It is anticipated to evolve as product development progresses, but will initially serve as a guideline to kickstart the development process.

Considering the complexity of the augmented reality (AR) interface, the initial product will feature a physical haptic screen, although one far superior to the braille screen in the prototype. Although seemingly different, this screen is a crucial step towards the eventual AR interface, enabling both technological and interaction- and ergonomics-based research necessary for the AR system.

8.1 TOWARDS THE INITIAL PHYSICAL PRODUCT

In this phase, developing the first version of the product is the primary goal. This version includes a physical screen with an integrated camera and sensor system. The development focuses on two main aspects: enhancing the interaction with the Dynamic Tactile Map (DTM) and advancing the underlying technology.

The interaction with the DTM requires extensive design research and experimentation with the target group using more advanced

prototypes in more representative and complex scenarios. In parallel, the haptic interface technology is advanced towards market-readiness, alongside the development of a specialized system for environmental mapping and a dedicated chip to handle this processing-intensive task.



Figure 8.1 Impression of the initial, physical product

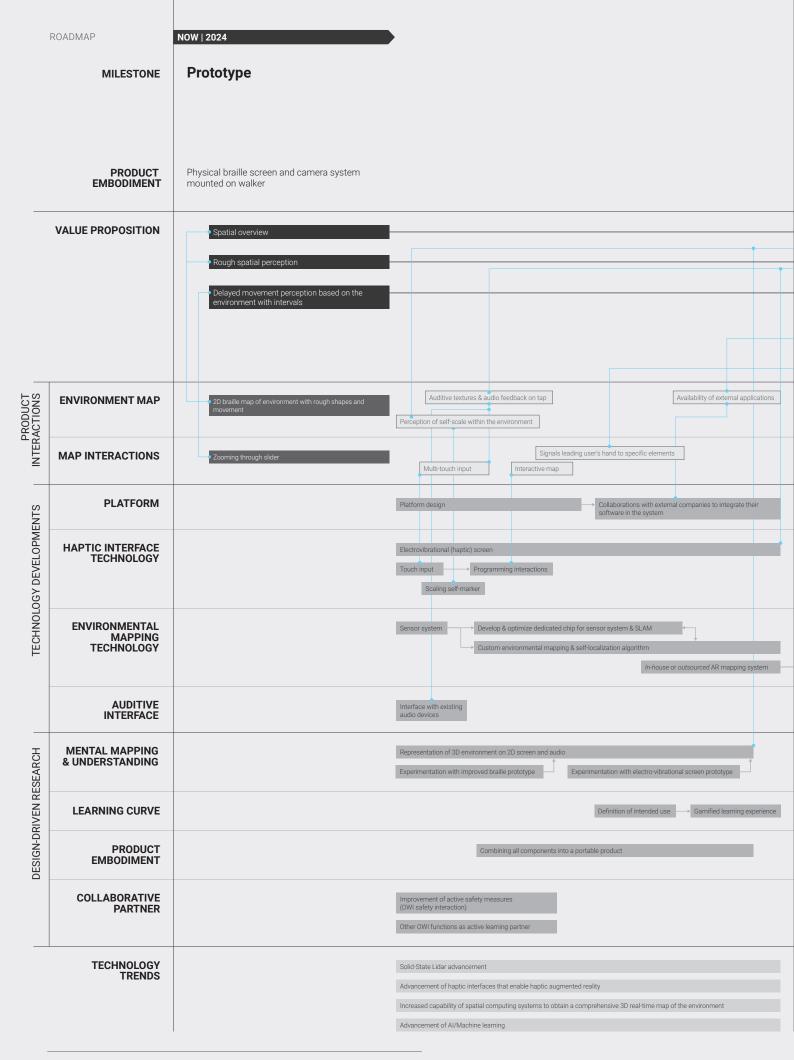


Figure 8.2 Tactical roadmap

DEVELOPMENT OF THE INTERACTION

Because there is still so much to understand about this new mode of environmental perception, extensive experimentation with an advanced prototype, similar to the experiment with the DTM prototype (as seen in figure 8.3 on the right) is essential. This prototype can make use of the same hardware, but it should have more stable self-orientation, and a higher refresh rate (updates were coming up for the DotPad that establish this). Such improvements allow for more in-depth studies, building upon the experiments performed with the DTM prototype, on environmental understanding, self-orientation, movement with the map, and cognitive challenges VIPs face, such as interpreting reactionary environmental motion of the map. Longer experimentation periods will also shed light on the learning curve associated with use of the DTM.

A better understanding of these topics is required to improve the interface and the way that the environment is depicted on the map, and it thus forms an important input for the development of the technology. Therefore, it is important to perform this research as early-on as possible.

LATER DEVELOPMENT STAGES

As development progresses, focusing on the overall experiential impact is crucial. Studying aspects like perceived overview and its resulting confidence in movement, and environmental engagement will inform design improvements. In this stage, defining and testing intended use strategies, such as map-based exploration, navigation and movement, with VIPs is allows alignment of the product with their needs and preferences. With a definition of intended use, the learning process can be designed. The learning process for new users should be gradual, introducing functions as users become more proficient, as they will inherently need to adapt to and learn to work with the product. A gamified approach, as discussed in chapter 3, could be effective, where users unlock advanced functions progressively.

To bring a market-ready dynamic tactile map to fruition, this design research is essential, as it underpins the design and development of the technology.

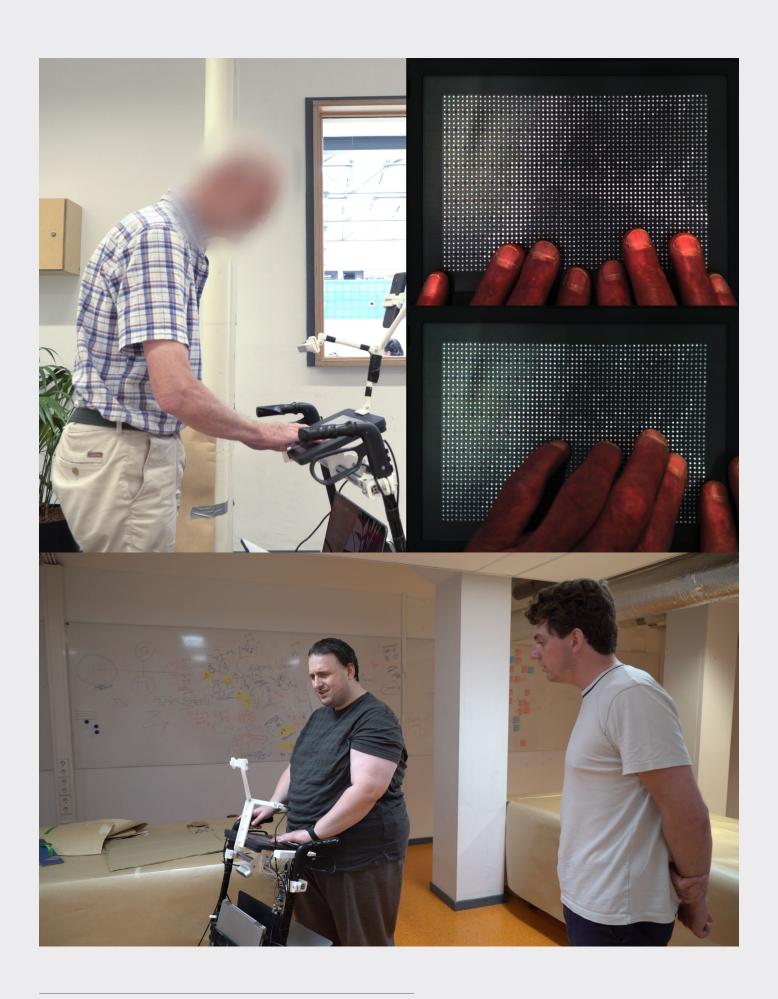


Figure 8.3 The impression of the experiment with the DTM prototype

DEVELOPMENT OF THE TECHNOLOGY

In this stage, the focus is on developing and refining technologies for environmental mapping and the user interface, progressing them towards market readiness.

ENVIRONMENTAL MAPPING SYSTEM

A dedicated system for environmental mapping and self-orientation will need to be developed. This system will scan and map the environment in real-time while simultaneously determining its own location and movement within it. It then executes environmental recognition algorithms and translate this information into a dynamic map for the haptic screen. Compared to the DTM prototype, this system requires the capability to map environments from greater distances, with more accuracy, speed, and with the ability to recognize the world and subdivide it into meaningful components for the map.

STRATEGY FOR DEVELOPMENT

Collaboration with Martin Klomp, a cognitive robotics expert at Delft University of Technology, leads to the formation of a development strategy of this system that involves three key components: the sensor system, the mapping algorithm, and the development of a dedicated chip.

SENSOR SYSTEM

First, the sensor system is defined. A fused system combining multiple sensors such as RGB-depth cameras, LiDAR, and an inertial measurement unit (IMU) is proposed, but further research and expert consultation is necessary. Inspiration can be drawn from sectors like self-driving cars, augmented reality, and robotics. For instance, Apple's Vision Pro augmented reality headset, which combines

as many as 12 cameras, five other sensors, and six microphones, seen in figure 8.4 (Apple. 2023), offers useful inspiration.

DEDICATED CHIP

A dedicated chip is likely necessary due to the significant processing power required for real-time environmental mapping. An example of this strategy can be seen in Apple's Vision Pro, in figure 8.4 on the right. This product features Apple's new R1 chip, that fully takes over sensor reading and algorithms related to the system's self-orientation. This chip is optimized for specific types of calculations, offering higher efficiency and performance compared to a general-purpose CPU and reducing load on the main CPU (Patently Apple, 2023), which can then be used more efficiently for general-purpose applications, such as the Object with Intent overlay of the map, or custom navigation applications. Martin Klomp suggests starting with an FPGA (Field-Programmable Gate Array) for developing this chip, owing to its customizable nature and suitability for prototyping.

SELF-LOCALIZATION AND MAPPING ALGORITHM

The development of the mapping algorithm runs in parallel. This algorithm will convert sensor data into a real-time 3D map and perform self-localization within this environment. Stable self-orientation is critical for accurate user positioning and minimizing mapping errors. Incorporating machine learning algorithms, such as Aslan's (2022) Visual–Inertial Odometry, can enhance the system's self-orientation stabilization at higher frequencies using cost-effective components.



Figure 8.4 Apple Vision Pro's sensors and chips (Omdia analyst photo)

THE FIRST HAPTIC INTERFACE

In this phase, the haptic interface that displays the DTM is developed. A study is done into the potential interface technologies, through internet research and collaborations with TU Delft Haptics Lab and Yasemin Vardar. This research can be found in Appendix K. The realization of this advanced haptic screen can be achieved either through in-house development, potentially in collaboration with research institute such as the TU Delft Haptics Lab, or by partnering with a specialized haptic screen developer. The availability of such an interface will enable more advanced prototypes and new design research with a better version of the DTM.

Based on the findings from the DTM experiment, this enhanced haptic interface should provide a high-resolution map with greater detail, allowing users to perceived more detailed overviews of the environment and better recognize environmental elements, facilitating the identification of landmarks, destinations, and other significant features. The interface must also clearly display movement at a high frequency. Also, the device should feature a self-marker that scales along with the map's level of zoom, that is able to clearly convey the user's own scale within the environment.

The research into potential interface technologies points towards the electrostatic display as the most promising option (as . This display offers higher frequency and resolution, for real-time movement perception and creating a more detailed map. The ability of this technology to simulate textures presents a more vivid environmental representation compared to the braille screen.

However, there are still significant challenges to overcome with this technology, particularly in accurately conveying shapes and edges. Vardar (2023) states the research group's goal of achieving "fingertip haptic feedback that feels realistic – no longer shaking an entire device – and can be felt by all fingers, whether they are stationary or moving". In this phase, the technology needs to be advanced to the point where it meets the defined qualities. Important design research with this technology assesses VIPs capability to understand and recognize environments using this screen and their ability to perceive motion in the environment.

When this is combined with audio feedback, it forms a well-rounded environmental perception tool. Therefore, concurrently, the development of effective auditory feedback is essential.

During the final stages of this phase,the embodiment for the product can be designed.

A PLATFORM FOR TRAVEL

The product should not be considered a standalone product but rather a platform. As described later in the discussion section, the integration of navigation applications will be very important. Integrating with established services like Apple Maps or BlindSquare would enable a more seamless process of travel.

However, many more applications are imaginable that could integrated within the system. For instance, integrating public transportation services into the platform would

further enhance the independence for VIPs. By allowing third-party developers to create and integrate their applications, the platform could continuously evolve, adapting to new technologies, user feedback, and emerging needs of the VIP community.

Viewing the product as an open platform that gives users to access a wide range of navigation tools and other services results in a more complete, multifunctional and adaptable solution that, rather than competing with other assistive solutions, integrates them into a more integrated solution.



Figure 8.5 Impression of the landing page for external developers

8.2 TOWARDS THE AUGMENTED REALITY SPATIAL EXPERIENCE

In the second phase, the product is advanced into the augmented reality system shown in the ISE concept. The embodiment of the product shifts to a head worn augmented reality glasses and a hand worn haptic interface. In this phase, the product will evolve towards an augmented reality system that places the map within the physical environment, that makes use of a multisensory 3D map for environment perception. This promises a much more natural awareness of the environment that allows the user to engage with it and become even

more confident in their movement and, in turn independent.

Advancing the product to this stage requires significant design and technological research. Although the technologies envisioned in the future concept are currently in development, they are grounded in realistic technological research and development, and are stimulated by recent market trends. The substantiation can be found below, in the technological development section.

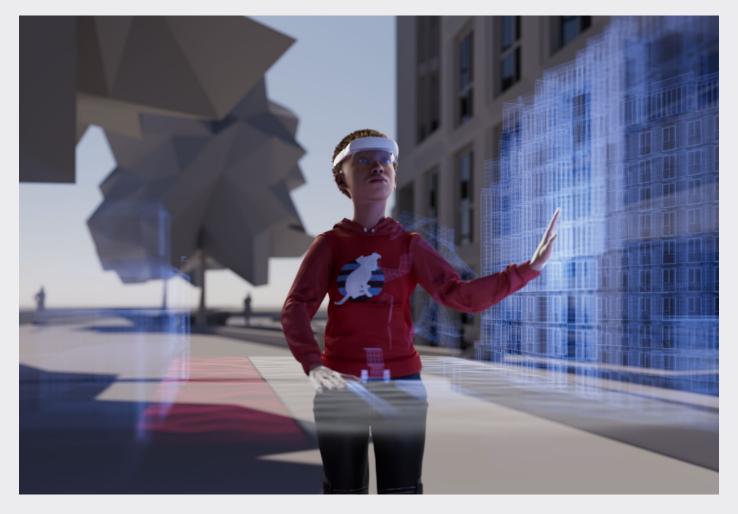


Figure 8.6 The augmented reality technology

DEVELOPMENT OF THE INTERACTION

During this stage, significant challenges will need to be overcome in the process of environmental perception and affiliated strategies of reading environments, orientation and movement. The augmented reality system enables similar strategies, such as reading the environment through its spatial layout and tracking movement of the environment, however the translation to 3D requires significant design research, to understand the experience of the user and their capabilities to do this.

For example, topics such as perception of the movement of upcoming geometry should be studied, to see if users are able to do this with the 3D map.

MAPPING CHALLENGE

An important problem to address in this phase with respect to the interaction between user and the 3D map is the challenge in environmental mapping that arises from the fact inability to perceive space within the body's, which represents the space nearest to the user. A remapping is required that displaces this space towards the perceptible space around the user, to a diameter that extends beyond the body. However, this distorts the space from its true-to-nature representation, potentially adding a layer of difficulty in map reading. The impact of this distortion is difficult to determine without practical testing, and further research is required to understand how this remapped space is experienced by VIPs, and this topic should carefully be studied when designing the interaction with the augmented reality map.

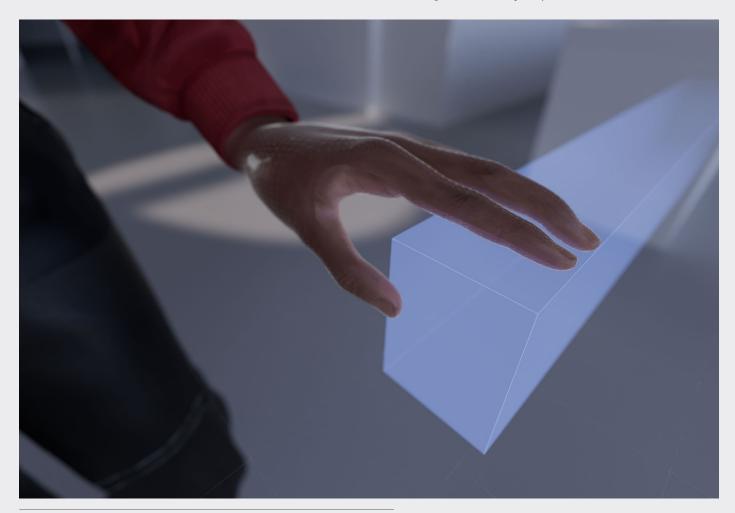


Figure 8.7 Tracking interaction in the augmented reality concept

DEVELOPMENT OF THE TECHNOLOGY

In this phase, the technology is advanced towards an augmented reality map that uses haptic gloves or some other haptic interface for the perception of the 3D map, and either uses an external AR headset or a custom system for environmental mapping and finger tracking for the virtual haptic interface

During the phase, significant technological advancements need to be made, that enable this augmented reality system and some important decisions need to be made, especially considering the technology applied for the environmental mapping and self-orientation technology.

ENVIRONMENT MAPPING AND SELF-ORIENTATION TECHNOLOGY

Systems capable of spacing computing and environmental awareness are increasingly becoming mainstream and see rapid advancement due to their application in markets such as robotics augmented reality and self-driving cars. This is exemplified by the launch of Apple's Vision Pro which Apple describes as the beginning of the "era of spatial computing" (Apple, 2023).

The progression of these technologies suggests that available technologies for the environmental mapping system will become better and cheaper. However, it also implies that mainstream technologies are likely to emerge that could fulfill the environmental mapping and self-orientation needs of the system.

Products such as the Apple Vision Pro apply very similar technology compared to the environmental mapping system of the DTM, and this overlap raises a crucial question: if users already possess technologies such as AR glasses that are capable of environmental mapping, should a new, custom system be

introduced in the DTM that requires them to abandon these other products?

This dilemma leads to a pivotal decision: should we develop a dedicated system for ISE's environmental mapping, or should we integrate existing AR technologies? Both approaches have their merits.

Custom-built technology might result in a more sophisticated and cost-effective solution, reducing the financial burden on VIPs who might otherwise need to purchase more expensive products to utilize the AR map. Additionally, relying on a proprietary system reduces dependency on external technology, which is beneficial from a business standpoint.

On the other hand, utilizing existing, mainstream technologies fits better with the intention of centralizing technologies, as described in chapter 3, and could reduce the overall costs if the VIP already possesses such mainstream technology.

Given these considerations, the current direction for the ISE concept involves using a readily available mainstream AR headset, equipped for comprehensive real-time 3D environmental mapping. However, this topic demands careful consideration of factors like user convenience, business implications, and the potential impact on the overall user experience for VIPs.

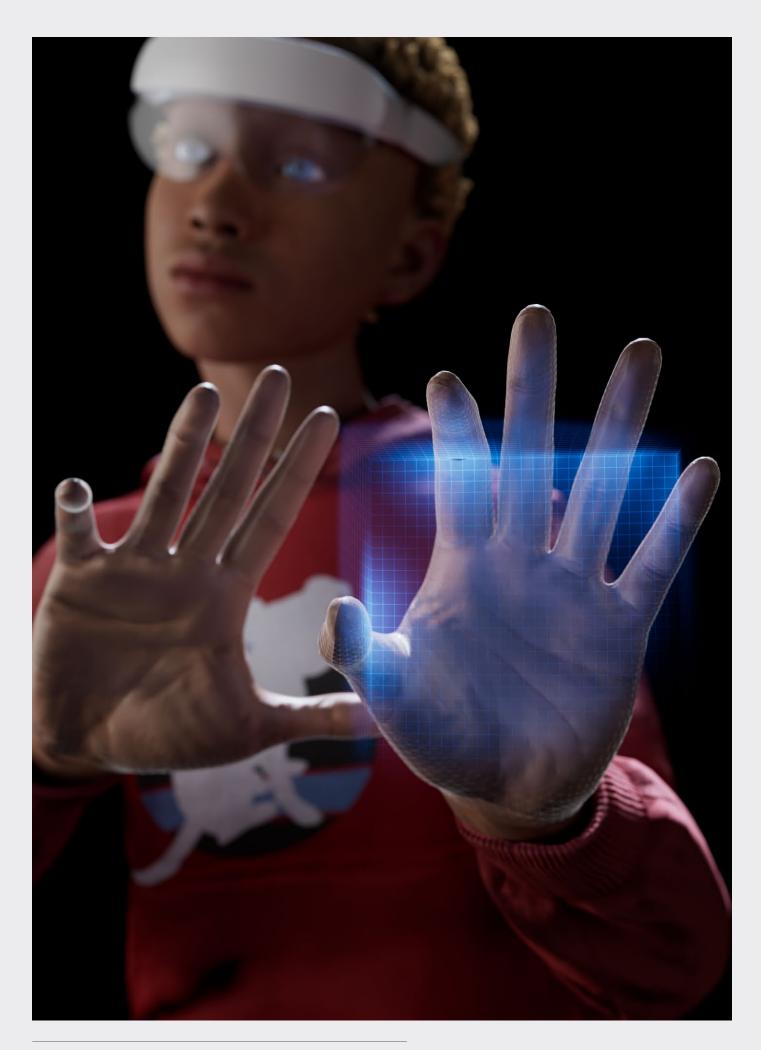


Figure 8.8 The haptic interface of ISE

HAPTIC AR INTERFACE

This development phase focuses on evolving the interface into a Haptic Augmented Reality (AR) system. This technology facilitates a comprehensive 360° perception of a 3D map using interfaces like haptic gloves. This interface should provide users with detailed perception of 3D geometry in the world along with their movement, textures, temperatures. The AR map is further enhanced with auditory feedback, creating a richer worldview.

Although such technology might seem futuristic, the field of Haptic AR is growing rapidly, together with advancements in standard (visual) AR. Companies like SenseGlove and WeArt have already introduced products capable of simulating 3D shapes, textures, and surface temperatures.

Currently, these devices are somewhat bulky and conspicuous, as can be seen in figure 9.9 and 9.10, however, ongoing development focuses on making such haptic AR technologies non-invasive, compact and userfriendly. An example of this is the technology by Tanaka (2023), seen in figure 9.11, that provides electrotactile feedback without obstructing the palm of the hand by "applying electro-tactile stimulation only to the back of the hand and to the wrist".



Figure 8.9 The Senseglove Nova 2 (Senseglove, 2023)



Figure 8.10 The Weart (Weart, 2023)

Figure 8.11 Non-invasive haptic interface technology by Tanaka (2023)

8.3 BUSINESS MODEL

The concept of a dynamic tactile map have great potential for a business model that revolves around its capability to perceive environments in 3D and generate extensive live data about public spaces. The system collects valuable environmental data as users navigate various spaces. a strong market position should be secured in the initial product stage where the system makes use of an in-house built system that allows for the rights to the data. This data, anonymized to protect user privacy, can be a valuable asset for companies and can be monetized, of course taking ethical considerations such as user privacy into account:

PARTNERSHIPS WITH MOBILITY AND URBAN PLANNING ENTITIES

The 3D environmental data can be invaluable for city planners and smart city initiatives. By providing detailed, real-time 3D maps of public spaces, this data can help in designing more accessible and efficient urban environments. Partnerships with municipalities and urban development projects can be formed where this data contributes to ongoing city planning and infrastructure projects.

COLLABORATION WITH MAPPING AND NAVIGATION COMPANIES

The detailed 3D data collected by the product is a significant asset for companies specializing in digital mapping and navigation solutions. Licensing this data can enhance their existing databases, especially in adding a layer of 3D spatial awareness and real-time updates.

ENVIRONMENTAL DATA ANALYTICS

The 3D data generated by the product can be analyzed to provide insights into pedestrian traffic patterns, environmental changes, and urban layout efficiency. This service can be offered to government bodies, research institutions, and private companies interested in urban studies and public space design.

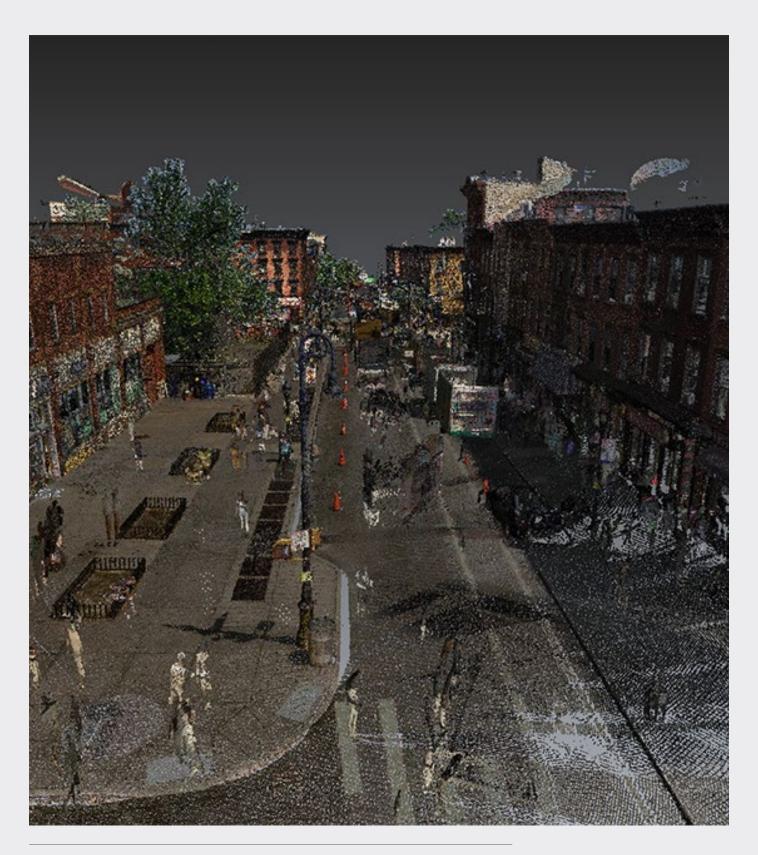


Figure 8.12 Environment scan generated through LiDAR (Befores & Afters, 2020)

9 DISCUSSION

This section evaluates the final outcome of the project in relation to the initial project's goals, design vision, reflects on its relevance and limitations. Finally, a general reflection by the student on the project is presented.

9.1 REFLECTION ON PROJECT OUTCOMES

This project set out to approach the design problemof mobility for VIPs from a different angle, shifting the lens from solely functional aspects, towards integration of psychosocial elements into the design of assistive technology. This approach not only aimed to enhance the physical mobility of VIPs but also sought to empower them psychologically and socially in their environments.

In the initial phase, the research placed special emphasis on psychosocial aspects, analysing them separately from the functional process of Mobility of VIPs. This identified the prevalent issue of high alertness due to fear of hazards and disorientation. This insight shaped the design vision and goal, aiming to reduce the vigilant state of mind through enhanced environmental perception that leads to intuitive environmental overview, enhancing their travel safety and efficiency. This capability was expected to foster confidence and independence, allowing VIPs to become engaged with the world, rather than viewing mobility as a must that sometimes was necessary.

reflecting on the final stage of the prototype, it struggled with still significant problems that had to do with functional usage of this prototype. These issues limited our ability to fully assess the psychosocial impact of our design. Nevertheless, early observations suggest that an increased environmental overview could potentially reduce the need for heightened alertness. Our experiments showed promise in this regard, indicating that our envisioned future concept focusing on enhanced perception is a step in the right direction.

Another cornerstone of our project was the amalgamation of technological advancement with user-centered design principles. The construction and testing of a functional prototype underscored the success of this approach. Our roadmap for future development emphasizes the continuous alignment of technology with human-centric research.

In summary, the project's focus on psychosocial aspects proved relevant as it led to the identification of these relevant user needs, that are widespread among the VI population, yet that arre commonly overlooked in academic research or design of contemporary technologies. This led to the development of a transformative design vision and a product and conceptual technology that emphasises these considerations. While the full impact of this technology on user needs awaits further research and development, our initial findings with the prototype are promising, showing signs of potential value to the VIPs due to increased overview during movement.

Although the technology is still in its cradle, the research raises hopes for a future where assistive technology offers more than mobility, and promises an enriched, confident, and engaged life experience for the visually impaired.

9.2 RELEVANCE

INTEGRATION OF IPD AND DFI

Aligned with the Faculty of IDE's three pillars of design – human, technology, and business - this project advocates for an extensive integration of these elements, that pays special attention to 'soft', experiential themes. Its approach It underscores the intertwined nature of technological advancement, user research, and business strategy, recognizing that these aspects are not standalone but deeply interconnected. This multidimensional approach, which balances the three pillars of design, is at the heart of the project. However, it must be recognized that the strategic, business aspect of the conceptual technology is somewhat underdeveloped at this stage. Given the technology's early stage, the primary focus remains on its usability and feasibility. This approach is sensible, as researching the technology's potential and value proposition are an important part of the formation of a business strategy.

The project employs a diverse array of research methodologies. This spectrum ranges from low-fidelity, improvisational methods in the OWI framework's research-driven design, to creating a functional electronic prototype of the DTM and conducting experimental trials with VIPs. The extensive initial-phase research, in which the designer attempted to deeply personally immerse in the design problem by getting close to the target group, and a design-centric approach, combined with solid technological development, arguably leads to the conclusion that the project is successful in its initial goal of weaving together user-focused, rapid design and research with comprehensive technological innovation.

RELEVANCE FOR ROYAL VISIO, ACADEMIC FIELD AND THE VI MOBILITY MARKET

The project advocates for a paradigm shift in mobility research and design, emphasizing holistic consideration of VIPs' experiences beyond functional and medicalized perspectives. By advocating for empathy and understanding of emotional needs by the designers of new technology, the project has raised critical questions and provided a new lens for future academic research and design practices in the field of assistive technology.

Extensive research phase that focuses on 'soft' topics which may seem counterintuitive in a fast-paced design process, however, as shown in this project, provides invaluable insights that allowed for design goals that align with user's core values. Royal Visio should actively stimulate the assumption of such an approach in the world of VI mobility because of their powerful position within the market and connections to developers. Royal Visio has the potential to become a leading advocate for this empathetic and holistic approach in the field, which fits well with their identity as an empathetic organisation, as seen in the internal analysis in Appendix A.

This is also relevant for the academic field. The research highlights the importance of considering the emotional and experiential impacts in the lives of individuals with visual impairments and the need of researchers to deeply and personally immerse themselves in the world op vips, prompting a reevaluation of how research into the design of assistive technology is done. The research has uncovered vital psychosocial factors, indicating a need for further investigation in this area. Future research should ideally recognize and expand upon these findings.

PRODUCT RELEVANCE

The relevance of this product in the current technological landscape, particularly in the realm of assistive technology for the visually impaired, is multi-faceted. While acknowledging the ongoing advancements in visual prostheses, which could potentially render the current product obsolete, the project recognizes its significant and immediate relevance in the present context.

The prospect of visual prostheses, connecting environmental sensing directly to the brain, indeed presents a revolutionary leap. However, after thorough consultation with leading researchers in the field, it becomes evident that such technology, while promising, is realistically several decades away from commercial viability due to its complexity. This extended timeline not only grants the current product a substantial period of relevance but also emphasizes the immediate need for innovative solutions that can be implemented in the near future.

9.3 LIMITATIONS AND FUTURE RESEARCH

While the project has made significant strides, certain aspects were constrained by time and scope. Key recommendations for future research include:

PARTICIPANT GROUP LIMITATIONS

The research's reliance on a small, homogeneous participant group (n=7, all Dutch males) presents limitations in terms of diversity and representativeness. Additionally, the qualitative nature of the research introduces potential biases, and the absence of testing in more realistic scenarios with traffic participants remains a significant limitation. In future research, efforts should be made to overcome these limitations.

NAVIGATION

The project focuses on bringing environmental awareness, rather than on navigation, because i wanted to improve the Perceptive capabilities of vips, so that they do not need navigation for smaller scale situations such as hospitals or lobbies, in the same way that site that people also do not need navigation for such tasks.

However, recognizing the practical needs of VIPs, especially for larger-scale routes, integrating navigation capabilities into the system is essential. Given the potential of the Dynamic Tactile Map (DTM) to become the primary tool for spatial perception, incorporating navigation functions within this

product would be superior to current strategies of navigation, where navigation instructions and environmental perception, which happens primarily through the cane, are separate processes. Thus, in further development, navigation functionality must be incorporated in the product, as also described in the roadmap.

SIGNALLING FUNCTION

Incorporating a signaling feature into the DTM is crucial for the safety of VIPs. This function plays a vital role in ensuring the safety of VIPs by alerting other traffic participants to their visual impairment. It alerts other road users to their presence, a requirement often stipulated by insurance companies. This is essential since DTMs may alter how VIPs are perceived, making them less recognizable as visually impaired, which might necessitate a more pronounced signal.

This signalling mechanism should be carefully designed, taking into account the perspectives of various stakeholders, including insurance agencies and regulatory bodies and, above all, the VIPs themselves: It is crucial to ensure that the new signaling method does not cause discomfort or stigma, a commonly known barrier for the adoption of technologies but also of the white cane. However, considering that the necessity of the signalling function stems from the VIPs' reduced ability to perceive and react to potential dangers and the goal of the technology to enhance this

awareness and VIPs' ability to react to such dangers, the DTM might deprecate the need for a signaling mechanism.

This complex topic will require careful design, research and negotiation with official parties and ensurance companies and collaboration with the target group. For these reasons, the signalling function is not considered during this project, but should be an important topic in the further design of the technology.

INTERACTION WITH OTHER TRANSPORTATION MODALITIES

Interactions with other transportation modalities his crucial in mobility. in this project, only walking mobility is considered. however in further development of this conceptual Direction the interaction with these other mobility's should be considered. ideally, the product works fluently with these other modalities and integrates with them, for example Allowing easy finding of best stops or helping the user easily and safely get on trains.

AI/ML ASSISTANCE, LEARNING SYSTEM

An important new trend in technology is the application of machine learning algorithms that enables smoother interaction by the device with the user, for example as an conversational agent. this topic is not considered in this project, however in future development of this technology machine learning algorithms can prove beneficial, for example in helping the user learn to use the device and in its interaction with the user as an OWI.

CLOUD COMPUTING

To reduce the required processing power and power usage of the product, computations on sensor data can be performed remotely, through a cloud computing infrastructure. this, however, requires the creation of such an infrastructure and requires the device to be connected to the internet in order to function. when further developing this system, this tradeoff should be carefully considered.

9.4 REFLECTION

As I embarked on this project, I was driven by a deep passion for advancing assistive technology for VIPs in an empathetic manner and a desire to master the art of designing meaningful high-tech products through an integrated, human-centred design process and a symbiosis of both my master's degrees.

Reflecting on my journey, I see a significant evolution in my approach to design and research. I wanted to make use of my last opportunity to learn new things and improve my skills within the safe space of the faculty. I am very happy and excited that this graduation project allowed me to meet all of my goals. In this personal reflection, I elaborate on my experience of the graduation journey and on the personal ambitions defined at the start of the project. Here are some key areas of my personal growth:

EMBRACING THE RESEARCH-THROUGH-DESIGN PROCESS

I was eager to gain experience in creative facilitation and conducting generative sessions aimed at finding user values. By gaining experience in these areas, I wanted to become better equipped to manage an integrated design process on my own. The extensive experimentation with the prototype, a first in my experience, has profoundly enhanced my understanding of these experimental methods.

ADVANCING TECHNICAL SKILLS IN PROTOTYPING AND ELECTRONICS

The development of a functional tactile map prototype was a pivotal moment in my educational journey. By choosing to use the Robot Operating System (ROS), I ventured into uncharted technological territories. This decision dramatically broadened my technical skill set, deepening my understanding of sensor technology, algorithms, and computer systems. The hands-on experience with ROS and the iterative prototyping process were crucial in enhancing my proficiency in advanced electronics and software development.

The decision to develop a functioning tactile map prototype using the Robot Operating System (ROS) was a leap into unfamiliar territory. This experience drastically enhanced my understanding of sensor technology and software-related topics such as computer memory.

LEARNING THROUGH CHALLENGES

The journey wasn't without its challenges. I faced moments of doubt, especially when trying to learn new technological skills and methodologies. However, this proved a great learning opportunity, reinforcing my resilience and adaptability in the design process.

In conclusion, this project not only met my academic and personal goals but also broadened my understanding and skills in technology and design, marking a significant milestone in my educational journey.

THE IMPORTANCE OF CONSTANT CONCLUDING

Reflecting on my graduation project, I have learned a lot about the importance of working concisely and regularly synthesizing and drawing conclusions. The project aligned well with its initial objectives, though there were challenges in maintaining this focus throughout. The iterative nature of the work sometimes led to deviations, which, while informative, occasionally detracted from the project's core aims.

REFERENCES

The foundations of this report are anchored in a comprehensive set of literature sources. The full list of sources can be found in this chapter.

Abd Hamid, N. N., & Edwards, A. D. N. (2013). Facilitating route learning using interactive audio-tactile maps for blind and visually impaired people. *Extended Abstracts on Human Factors in Computing Systems (CHI EA '13)*. Association for Computing Machinery, New York, NY, USA, 37–42. https://doi.org/10.1145/2468356.2468364

Apple Inc. (2023). Introducing Apple Vision Pro. Retrieved January 3, 2024, from https://www.apple.com/newsroom/2023/06/introducing-apple-vision-pro/

Aslan, M. F., Durdu, A., Yusefi, A., & Yilmaz, A. (2022). HVIOnet: A deep learning based hybrid visual—inertial odometry approach for unmanned aerial system position estimation. *Neural Networks*, 155, 461-474. ISSN 0893-6080.

Athulya, N. K., Ramachandran, S., George, N., Ambily, N., & Shine, L. (2023). Enhancing outdoor mobility and environment perception for visually impaired individuals through a customized CNN-based system. *International Journal of Advanced Computer Science and Applications (IJACSA)*, 14(9).

Banovic, N., Franz, R. L., Truong, K. N., Mankoff, J. M., & Dey, A. K. (2013). Uncovering information needs for independent spatial learning for users who are visually impaired. *Proceedings of the 15th International ACM SIGACCESS Conference on Computers and Accessibility (ASSETS '13*). Association for Computing Machinery, New York, NY, USA, Article 24, 1–8. https://doi.org/10.1145/2513383.2513445

Befores & Afters. (2020, July 6). Tales from on-set: LiDAR scanning for Joker and John Wick 3. Retrieved Juli 12, 2023, from https://beforesandafters.com/2020/07/06/tales-from-on-set-lidar-scanning-for-joker-and-john-wick-3/

Beggs, W. D. A. (1992). Coping, adjustment, and mobility-related feelings of newly visually impaired young adults. *Journal of Visual Impairment & Blindness*, *86*(3), 136-140. https://doi.org/10.1177/0145482X9208600307

BlindSquare. (n.d.). About. Retrieved October 23, 2023, from https://www.blindsquare.com/about/

Brouwer, D. M., Sadlo, G., Winding, K., & Hanneman, M. I. G. (2008). Limitations in mobility: Experiences of visually impaired older people. *British Journal of Occupational Therapy*, *71*(10), 414-421. doi:10.1177/030802260807101003

Burton, M. J., Ramke, J., Marques, A. P., Bourne, R. R., Congdon, N., Jones, I., et al. (2021). *The Lancet Global Health commission on Global Eye Health: vision beyond* 2020. *The Lancet Global Health,* 9(4), e489-e551.

California Optometric Association. (n.d.). Vision Impairment and Blindness. Retrieved May 27, 2023, from https://www.coavision.org/m/pages.cfm?pageid=3625

Chanana, P., Paul, R., Balakrishnan, M., & Rao, P. (2017). Assistive technology solutions for aiding travel of pedestrians with visual impairment.

Journal of Rehabilitation and Assistive Technologies Engineering, 4. doi: 10.1177/2055668317725993.

PMID: 31186934; PMCID: PMC6453076.

Dot Incorporation. (n.d.). PAD. Retrieved August 26, 2023, from https://pad.dotincorp.com/

Dourish, P. (2001). Where the Action Is: The Foundations of Embodied Interaction. The MIT Press. https://doi.org/10.7551/mitpress/7221.001.0001

European Blind Union. (n.d.). Facts and Figures About Blindness and Partial Sight. Retrieved May 12, 2023, from https://www.euroblind.org/aboutblindness-and-partial-sight/facts-and-figures

FoneArena. (n.d.). Apple Vision Pro Price Features. Retrieved August 17, 2023, from https://www.fonearena. com/blog/395311/apple-vision-pro-price-features.html

Gleeson, B. J. (1996). A geography for disabled people? Transactions of the Institute of British Geographers, 21(2), 387–396. https://doi.org/10.2307/622488

Golledge, R. G. (1993). Geography and the disabled: A survey with special reference to vision impaired and blind populations. *Transactions of the Institute of British*Geographers, 18(1), 63–85. https://doi.org/10.2307/623069

GoodMaps. (n.d.). Enhance Your Venue. Retrieved January 7, 2024, from https://goodmaps.com/enhance-your-venue/

Kennisoverzicht. (n.d.). Kennisoverzicht [Knowledge Overview]. Retrieved May 12, 2023, from https://www.kennisoverzien.nl/

Koninklijke Visio. (2020). Visio - Jaarrekening 2020.

Koninklijke Visio. (2021). Compensatie 2; oriëntatie en non visuele waarneming.

Koninklijke Visio. (2022). Introductie op O&M.

Koninklijke Visio. (2023). Waarnemen en bewegen 2.

Koninklijke Visio. (n.d.). Een geleidehond aanvragen: Doen of niet?. Retrieved October 20, 2023, from https://kennisportaal.visio.org/nl-nl/documenten/ een-geleidehond-aanvragen-doen-of-niet

Koninklijke Visio. (n.d.). Een geleidehond aanvragen: Doen of niet? [Applying for a guide dog: To do or not?]. Retrieved August 12, 2023, from https://kennisportaal.visio.org/nl-nl/documenten/een-geleidehond-aanvragen-doen-of-niet

Kouprie, M., & Sleeswijk Visser, F. (2009). A framework for empathy in design: Stepping into and out of the user's life. *Journal of Engineering Design*, *20*, *437-448*. 10.1080/09544820902875033.

Laser Eye Surgery Hub. (n.d.). Visual Impairment & Blindness Data Statistics. Retrieved May 13, 2023, from https://www.lasereyesurgeryhub.co.uk/data/visual-impairment-blindness-data-statistics/

Life Without Barriers. (n.d.). Four Things You Should Know About Guide Dogs. Retrieved June 17, 2023, from https://www.lwb.org.au/news/fourthings-you-should-know-about-guide-dogs/ MacEachren, A. M. (1992). Application of environmental learning theory to spatial knowledge acquisition from maps. *Annals of the Association of American Geographers*, *82*(2), 245-274. DOI: 10.1111/j.1467-8306.1992.tb01907.x

Marston, J., & Golledge, R. (2003). The hidden demand for participation in activities and travel by persons who are visually impaired. *Journal of Visual Impairment & Blindness*, 97, 475-488. 10.1177/0145482X0309700803.

Mispelblom Beyer, J. Q. (2019). Tact.

National Federation of the Blind. (n.d.). Blindness Statistics. Retrieved May 13, 2023, from https:// nfb.org/resources/blindness-statistics

Oogfonds. (n.d.). Feiten en cijfers. Retrieved May 17, 2023, from https://oogfonds.nl/onze-ogen/feiten-en-cijfers/

Oogfonds. (n.d.). Slechtziend [Visually Impaired]. Retrieved May 13, 2023, from https://oogfonds. nl/visuele-beperkingen/slechtziend/

OrCam. (n.d.). Home. Retrieved October 19, 2023, from https://www.orcam.com/nl-nl/home?utm_source=landing-page&utm_medium=redirected-from-404

OrCam Technologies. (n.d.). Explore OrCam. Retrieved October 15, 2023, from https://explore.orcam.com/

Passini, R., Dupré, A., & Langlois, C. (1986). Spatial mobility of the visually handicapped active person: A descriptive study. Journal of Visual Impairment & Blindness, 80(8), 904-907. https://doi.org/10.1177/0145482X8608000809

Patently Apple. (2023, September). Apple has filed for a wide range of new trademarks including the Apple Vision Pro related R1 chip, carbon neutral, and more. Retrieved November 14, 2023, from https://www.patentlyapple.com/2023/09/apple-has-filed-for-a-widerange-of-new-trademarks-including-the-apple-vision-pro-related-r1-chip-carbon-neutral-and-mor.html

Rozendaal, M., van Beek, E., Haselager, P., Abbink, D., & Jonker, C. M. (2020). Shift and blend: Understanding the hybrid character of computing artefacts on a toolagent spectrum. *Proceedings of the 8th International Conference on Human-Agent Interaction (HAI 2020)* (pp. 171-178). Association for Computing Machinery. https://doi.org/10.1145/3406499.3415066

Rozendaal, M. C., Boon, B., & Kaptelinin, V. (2019). Objects with intent: Designing everyday things as collaborative partners. *ACM Transactions* on *Computer-Human Interaction*, *26(4)*, Article 26. https://doi.org/10.1145/3325277

SenseGlove. (n.d.). Nova 2. Retrieved November 7, 2023, from https://www.senseglove.com/nova-2/

Seybold, D. (2005). The psychosocial impact of acquired vision loss—Particularly related to rehabilitation involving orientation and mobility. *International Congress Series (Vol. 1282, pp. 298-301)*. ISSN 0531-5131, ISBN 9780444520913.

St. Albert Gazette. (n.d.). Poole boardwalk gets guide for the blind: BlindSquare, Brittain, Bent. Retrieved June 13, 2023, from https://www.stalbertgazette.com/local-news/poole-boardwalk-gets-guide-forthe-blind-blindsquare-brittain-bent-4458884

Tanaka, Y., Shen, A., Kong, A., & Lopes, P. (2023). Full-hand electro-tactile feedback without obstructing palmar side of hand. *Proceedings of the 2023 CHI Conference on Human Factors in Computing Systems (CHI '23)* (*Article 80, pp. 1–15*). Association for Computing Machinery. https://doi.org/10.1145/3544548.3581382

Tierney, P., & Farmer, S. M. (2002). Creative self-efficacy: Its potential antecedents and relationship to creative performance. *The Academy of Management Journal*, *45*(*6*), 1137–1148. https://doi.org/10.2307/3069429

TomTom. (n.d.). Tactile Mapping: Helping the Blind Find Their Way. Retrieved December 23, 2023, from https://

www.tomtom.com/newsroom/explainers-and-insights/ tactile-mapping-helping-the-blind-find-their-way/

TU Delft. (n.d.). MSc Design for Interaction. Retrieved January 7, 2024, from https://www.tudelft. nl/onderwijs/opleidingen/masters/msc-designfor-interaction/msc-design-for-interaction

TU Delft. (n.d.). MSc Integrated Product Design.
Retrieved January 7, 2024, from https://www.tudelft.
nl/onderwijs/opleidingen/masters/msc-integratedproduct-design/msc-integrated-product-design

TU Delft Design Labs. (n.d.). Expressive Intelligence Lab. Retrieved January 7, 2024, from https:// delftdesignlabs.org/expressive-intelligence-lab/

Unknown photographer. (2023). Omdia analyst at Apple Worldwide Developers Conference [Photograph]. Retrieved January 6, 2024.

Unknown uploader. (n.d.). [Video file]. Retrieved January 7, 2024, from https://www.youtube.com/watch?app=desktop&v=9867XDW4k98

Walker, B. N., & Lindsay, J. (2006). The effect of a speech discrimination task on navigation in a virtual environment. Proceedings of the Human Factors and Ergonomics Society Annual Meeting (Vol. 50, No. 16, pp. 1538-1541).

Weart. (n.d.). Force Feedback. Retrieved December 3, 2023, from https://weart.it/our-technology/force-feedback/

Zhang, Y. and Harrison, C. 2015. Quantifying the Targeting Performance Benefit of Electrostatic Haptic Feedback on Touchscreens. *Proceedings of the ACM International Conference on Interactive Tabletops and Surfaces*. ITS '15. ACM, New York, NY. 43-46.

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