ISE

IMMERSIVE SPATIAL EXPERIENCE

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

APPENDIX

Master's Thesis
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APPENDIX A INTERNAL ANALYSIS

Royal Visio is this project's client. Royal Visio is a large Dutch foundation with a long-standing commitment to empowering individuals with visual disabilities to lead independent and confident lives. For more than two centuries, they have been providing valuable information, advice, mentoring, revalidation, education, housing and research.

METHOD

An internal analysis is conducted to comprehend the organisation's identity, goals, and values, align project efforts, determine the project team's position, funding sources, and their concerns, understand decision-making processes, recognise organisational strengths and weaknesses in product development, gauge product market experience, and identify relevant expertise within Visio for project assistance.

VISIO'S IDENTITY, GOALS AND VALUES

Koninklijke Visio has worked to improve the lives of the visually impaired for over 200 years. They work together with other care organisations and with individual clients (which counted over 16000 in 2020). Their headquarters are located in Huizen, and the company has +- 2800 employees, most of which are situated in the Netherlands.

"Enabling participation for everyone"

Koninklijke Visio's goal is to ensure an independent and confident life for "partially sighted and blind people and people with other visual impairments, whether or not in combination with disorders of an auditory, psychological, neurological, cognitive or other nature, in the most general sense" through specialised expertise. (Royal Visio, 2020)

They support the visually impaired as well as those people around them, either professional or non-professional. To do so, they offer the following services:

- providing information and advice
- conducting research
- mentoring
- revalidation
- education
- providing housing

They support the visually impaired to discover their potential, stimulate them to learn new skills and build positivity. For mentors, they provide information and education/training, as well as space and trust to undertake business attempts. In this, they are focused on results, consistency and reliability and personal approach.

Royal Visio's mission is subdivided into 5 self-defined 'pillars':

1. Meaningful for our clients and students
2. Making a difference in society
3. Knowledge and expertise as an innovation accelerator
4. Working from inspiration
5. Impact from vital networks
6. Cooperative, connective culture

Specialised expertise is Visio's core value. To be able to provide this, they strive towards a knowledge-building and learning organisation and a connective culture in which professional knowledge and expertise are spread as much as possible.

This connective culture is reflected in the cooperations that Koninklijke Visio actively seeks with other organizations and the way in which they try to increase the visibility of their work: "Together we can achieve more for people with visual impairment".

They work together with large players in the sector to align research efforts. Together with Bartimeus, the Robbert Coppes Foundation and the MaculaVereniging, they initiated the 'sectorial expertise program Visual' for 2020-2022. Within this sectorial program, expertise departments of the four companies focus their research efforts together on five topics:

1. I am comfortable in my skin
2. The world is accessible to me
3. My possibilities and limitations are well understood
4. Improving diagnostics
5. Technology offers me opportunities

My project will be part of topic #5 'Technology offers me chances'

FUNDING AND POSITIONING OF THE PROJECT

ROYAL VISIO'S FINANCIAL STRUCTURE

KV is a large foundation with an annual revenue of €170M+ and an equity of €45M+. The overly largest part of this revenue is made in their healthcare activities.

As a foundation, they are not allowed to make a significant profit. As an 'Algemeen Nut Beogende Instelling' (ANBI, Public Benefit Institution), they may deduct donations from income and corporate taxes.They are heavily subsidised and receive financial support by the Wet Maatschappelijke Ondersteuning (Social Support Act) and jeugdzorg (youth care).

Royal Visio is backed by several foundations: Vrienden van Koninklijke Visio, Visio Foundation and Katholieke stichting voor blinden en slechtzienden. Together with Bartiméus, they provide full financial and secretatial support for the InZicht foundation, which aims to fund research. The management of these foundations sometimes overlaps with that of KV, with the chair of KV's board of directors, Margreeth Kasper de Kroon, for example being treasurer of the board of directors of the InZicht foundation.

The 'sectorial expertise program Visual' is subsidised with a total amount of €39M for the years 2020-2023 by the programme 'InZicht', which was initiated by the ZomMW foundation, which is funded by support foundations linked to Royal Visio and Bartimeus. ZonMW strives to "stimulate scientific research into the care, employment, education and rehabilitation of people with visual impairments, thereby improving the quality of life for this target group. In addition, InZicht aims to better connect scientific research to questions from practice" (InZicht, 2023). Their role in this programme is to 'issue calls for subsidies and monitor careful evaluation of research proposals submitted. On quality, as well as on relevance, so that the research meets the needs in the field.' (ZomMW, 2023). By definition, the board of the InZicht programme should contain 1 (out of 3) members from Royal Visio.

Funding for my project comes from the InZicht programme from ZomMW and connects to the "sectorial expertise program Visual' sectorial goals.

VISIO'S ORGANISATIONAL STRUCTURE AND PROJECT POSITIONING

KV consists of: The board of directors, the supervisory board (that monitors the board of directors), participation bodies for employees, clients, residents, pupils, parents and client representatives and the business units:

- Primary processes: Rehabilitation & Counseling (including intake), Education, Housing & Day Care
- Knowledge, Expertise & Innovation.
- Management Support, including Communication and Quality
- Internal Control.
- Support Services: Operations, HRM, Computerization & Automation

Within the organisation, I will be part of the 'Innovation' subbranch of the 'Operations, HRM, Computerization & Automation' branch of 'Supportive Services'.

They are certified CIIO: CIIO's own developed interpretation of the ISO 9001 standard for quality management system, aimed at 'knowledge-intensive service providers' for which they are annually monitored. CIIO has 6 pillars:

1. Heading (alignment with changing environment)
2. Organization
3. Core processes
4. People
5. Partners
6. Results

EXPERIENCE WITH BRINGING PRODUCTS & SERVICES TO THE MARKET

Visio develops services & methodologies, an example of which is 'Active Learning': "Making contact and discovering the world around you through play". For this, they developed a theory book and workbook with exercises.

They have some, but little experience with bringing products to market that result from their research projects. Their most important release is the SenseMath application, available in the App Store and Google Play Store, which allows visually impaired people to 'hear' mathematical functions.

CONCLUSIONS

ROYAL VISIO & PROJECT DENTITY, GOALS & VALUES

- Visio focuses on empowering VIPs by stimulating them to learn and becoming independent. My project will connect to this and join in this effort. I can expect to learn from Visio's professionals in early stage of project their approach how to achieve this goal.
- Royal Visio focuses on knowledge-sharing, transparant and visibility in research efforts, and they are well connected to the different large players in the sector work together closely and share knowledge extensively. This means that during the project, there is an opportunity to exchange knowledge, collaborate on and discuss project with Bartimeus, the Robbert Coppes Foundation and the MaculaVereniging. This means I can adopt an open and cooperative mindset and do not have to be protective of knowledge obtained or generated during the project.
- Visio's clients are not only visuelly impaired, but also people with multiple impairments.

PROJECT POSITIONING

- Visio is an affluent organisation with an annual revenue of €170M+
- The research is done in service of the 'Sectorial Expertise Program Visual' and falls within the subbranch'Technology offers me opportunity'.
- The project is funded by the InZicht subsidy by the ZonMW foundation, intended for this same sectorial expertise programe visual, with the same research goals.
- My team is part of the 'Innovation' subbranch of the 'Operations, HRM, Computerization & Automation' branch of 'Supportive Services'.
- Within Visio, the project is situated in the categories 'Assistive tools' and 'Touch and Braille'. However, team members mention that this subdivision is of little importance (Christiaan)

STRENGTHS & WEAKNESSES IN PRODUCT DEVELOPMENT

Visio has little prior experience with putting products to the market.

Visio is a large and affluent organization with extensive connection to and knowledge of the target group. This provides me with easy access to expertise and to the target group

IMPLICATIONS

- I will not target people with multiple impairments, to keep the project's scope manageable.

APPENDIX B
FACTS & FIGURES VISUAL IMPAIRMENT

The realm of visual impairment (VI) encompasses a diverse and nuanced spectrum, characterized by varying degrees and forms of visual disabilities. This complex landscape presents unique challenges and requirements in terms of mobility and everyday functionality. Recognizing the differences within the VI community is crucial for effective design. This section aims to demystify these differences between visual impairments, offering a detailed demographic analysis to understand the varying needs and contexts within this community.

DEFINITIONS

Visual Impairment refers to a reduction in a person's ability to see and perceive visual information, either permanently or temporarily, and can describe both blind and partially sighted individuals. The World Health Organization (WHO) categorizes visual impairment into two categories: distance and near-presenting vision impairment.

- Distance vision impairment is further subdivided into the following groups based on the remaining visual acuity:
- Mild – visual acuity worse than 6/12 to 6/18
- Moderate – visual acuity worse than 6/18 to 6/60
- Severe – visual acuity worse than 6/60 to 3/60
- Blindness – visual acuity worse than 3/60
- Near vision impairment is defined as having near visual acuity worse than N6 or M.08 at 40cm.

(World Health Organisation, 2023)

Next to remaining visual acuity, a visual impairment can take different shapes. While some individuals experience total blindness, others may have varying degrees of visual perception, such as limited ability to distinguish light and shadow, blurry vision, tunnel vision, or absence of central vision. The diverse range of visual impairments arises from different eye conditions, each of which results in distinct forms of visual distortion. These forms are described below, and an impression of their experience can be seen in figure ##.

1. Loss of Central Vision: A blur or blindspot, side (peripheral) vision remains intact. This makes it difficult to read, recognize faces and distinguish most details in the distance. Mobility, however, is usually unaffected because side vision remains intact.
2. Loss of Peripheral (Side) Vision / Tunnel vision: Loss of vision to one side or both sides or anything directly above and/or below eye level. Typically, loss of peripheral vision may affect mobility and if severe, can slow reading speed as a result of seeing only a few words at a time.
3. Blurred Vision: Blurred vision causes both near and far to appear to be out of focus, even with the best conventional spectacle correction possible.
4. Generalized Haze: Generalized haze causes the sensation of a film or glare that may extend over the entire viewing field.
5. Extreme Light Sensitivity: Extreme light sensitivity exists when standard levels of illumination overwhelm the visual system, producing a washed out image and/or glare disability. People with extreme light sensitivity may actually suffer pain or discomfort from relatively normal levels of illumination.
6. Night Blindness: Night blindness results in inability to see outside at night under starlight or moonlight or in dimly lighted interior areas such as movie theaters or restaurants.

(California optometric association, n.d.)

WORLDWIDE FIGURES

Despite the common misconception that vision impairment is a rare phenomenon, in reality, millions of people around the world struggle with it daily. Overall numbers of blind and visually impaired people continues to increase due to increased life expectancy, rise in the global population, and poor access to health care in low-income countries.

2.200.000.000	Visually impaired
237.000.000 ~ 11%	Moderate to severe cases
39.000.000* ~ 2%	Fully blind

*This is said to increase to 115.000,000, or almost triple in 2050

(World Health Organisation, 2023)

FIGURES IN THE NETHERLANDS

As expected by looking at the world map on visual impairment ##, the dutch VI population differs from the worldwide average. Because my project is situated in the Netherlands, it is important to understand the general buildup there.

> 300.000*	Visually impaired
200.000	Moderate to severe cases of VI
50.000	Fully blind

- Almost 2/3rd is female
- 1 in 3 children is nearsighted and at risk of becoming blind or visually impaired later in life
- Maculadegeneratie is the most common hereditary eye disease in the Netherlands.
- Three areas that are most influenced by VI
- Travel and relocation (70%)
- Feelings, time and energy (52%)
- Education, work and money (41%)
- In Europe, the unemployment rate of VI people of working age is high (75%).

(Oogfonds, 2023)

It can be observed that the total prevalence of VI is much lower, but that a much larger share (almost a third) is severely impaired relative to milder forms of VI. This can be explained by the better healthcare system: In the Netherlands, the population's eye health is monitored much better and people 'sound the alarm' much earlier due to easier access to medical specialists. Mild and starting vision impairments can be treated earlier and more often. What remains are the less-treatable severe eye conditions and a lower number of total cases of VI.

CAUSES OF VI

Some people are born with reduced sight, however the largest share acquires an eye condition later in life. There can be many different reasons a VI can arise, below an overview is shown of the leading causes of VI in percentages are (world health organisation):

Unaddressed Presbyopia	80.12%
Unaddressed Refractive Error	12.00%
Cataract	6.32%
Glaucoma	0.67%
Corneal Opacities	0.41%
Diabetic Retinopathy	0.29%
Trachoma	0.19%

(The International Agency for the Prevention of Blindness (IAPD Atlas), 2023)

SIGHT LOSS OVER THE AGES

Visual impairments are often progressive. Age-related eye conditions, affected by conditions such as macular degeneration or cataracts are the most common cause of sight loss in Europe. In the Netherlands, over 85% of the visually impaired population is over 50 years old.

There are no clear numbers of how many are born with a VI but this number is relatively small. In 2018, an estimation was made by Royal Visio that of all their clients, 2000 were under 18 years old. It can be safely assumed that only a small part of this group was actually born blind and that a larger share has acquired their VI lateron during life, e.g. by Juvenile macula degeneration.

INCREASED VI AND LESS TOOLS IN DEVELOPMENT COUNTRIES

There is a significant disparity in the prevalence of visual impairment (VI) across the globe, with low-income countries experiencing higher rates of VI. In these regions, millions of individuals suffer from preventable blindness caused by diseases. Such types of vision loss are termed as “preventable blindness.” As per the World Health Organization (WHO), almost 1 billion cases of VI could have been prevented or treated. The primary causes of these cases include near vision impairment caused by unaddressed presbyopia, cataracts, unaddressed refractive errors, age-related macular degeneration, glaucoma, and diabetic retinopathy. Improvements in and better access to treatment of preventable conditions have led to a reduction in the prevalence of visual impairments. For example, there has been a 24% decrease in the number of blind children since 1990, largely attributed to better management of measles and vitamin A deficiency.

In low-income countries, the lack of welfare leads to a scarcity of tools, including assistive technology and guide dogs, and training. Figure ## demonstrates that regions with the highest percentage of VI also have the smallest markets, implying a lower demand for assistive technology. The highest adoption rate of assistive technology is observed in North America and Europe, where training and assistive technology are more readily available.

CONCLUSIONS

The global prevalence of visual impairment (VI) is a significant and growing concern, affecting approximately 2.2 billion individuals worldwide. In the Netherlands, the prevalence of VI is relatively low at 1.7%, compared to the global average of 27.5%. This disparity is largely attributed to the nation's advanced healthcare system and early diagnostic capabilities. Despite the lower prevalence, moderate to severe VI and complete blindness are more commonly observed in the Dutch VI community.

Visual impairments predominantly result from progressive conditions, with a small fraction of the VI community being congenitally blind. The majority of those affected are over 50 years old, dealing with age-related visual deterioration. A notable gender disparity exists, with females constituting a larger proportion of the VI population (55% globally, and approximately two-thirds in the Netherlands). The unemployment rate among working-age visually impaired individuals is alarmingly high at 75%.

In contrast, low-income countries face a higher prevalence of VI, compounded by inadequate healthcare and limited access to assistive technologies and resources. These insights not only highlight the diverse needs within the VI community but also underscore the urgency for tailored and accessible solutions in both high- and low-income countries.

DESIGN IMPLICATIONS

Considering the diversity and complexity within the VI community, the design approach for this project will be highly interactive and collaborative, focusing primarily on the Dutch VI community. This choice is driven by the project's geographical constraints and the need for an immersive understanding of the target group's experiences and challenges.

The primary focus will be on individuals with moderate to severe VI and those who are completely blind. This includes both congenitally blind individuals and those who acquired VI later in life. Given that the latter constitutes a larger segment, special attention will be given to their unique needs and adaptation processes.

The project acknowledges the pressing need for affordable and accessible VI mobility tools in low-wage countries. However, due to the limitations in immersing in these contexts and the substantial implications for design, this aspect will remain outside the current project scope. Future explorations in this area are recommended, considering the high prevalence of VI and the scarcity of resources in these regions.

In summary, this project aspires to design solutions that are empathetic and inclusive, taking into account the diverse experiences of individuals with VI, with a particular focus on the Dutch context.

APPENDIX C VI MOBILITY

This phase involves:

- Literature Review: A comprehensive study of VIP mobility, examining both functional and experiential aspects, to establish a theoretical base.
- Interviews with VIPs: Conducting in-depth interviews with 8 VIPs, each lasting 1 to 1.5 hours, to gain personal insights into their mobility experiences and needs.
- Observation and Thought Experiments: Observing 4 VIPs in outdoor settings for 0.5 to 1 hour each, complemented by thought experiments to understand real-world mobility challenges.
- Consultations with Mobility Experts: Engaging with 4 mobility professionals to understand their expert perspectives and knowledge.
- Simulation Training Participation: Experiencing the challenges faced by VIPs firsthand through simulation exercises.
- Mobility Training Sessions: Attending 2 sessions where VIPs work with their mobility trainers to observe professional approaches to mobility assistance.

TRANSPORTATION MODALITIES

There are numerous ways to journey from point A to B, and the average trip often incorporates various modes of transportation. One can travel by foot, bicycle, car, public transportation, drive along with someone, etc. These different means are called transportation modalities. These diverse transportation options grant us the freedom to go wherever we desire, whenever we choose, and in the manner we prefer. A visual impairment influences and restricts these choices. For instance, VIPs are typically not permitted to drive motorized vehicles, and long journeys by foot are more difficult, in which case a taxi might be easier.

Mobility is a constant choice between modalities. Pedestrian mobility underlies and connects all of them: Walking is essential for tasks such as reaching public transportation, heading to a taxi, moving around one's home, and exploring one's surroundings. In certain scenarios, such as small and spontaneous trips, it's the most logical choice to travel on foot; for instance, one would not call a taxi just to visit the bakery at the corner of your street. For this reason, questions and concerns regarding pedestrian mobility are most common among individuals with visual impairments. (Royal Visio, 2021)

Therefore, this project focuses primarily on pedestrian mobility: Improving pedestrian mobility facilitates the overall journey and, in some cases, can eliminate dependence on other modalities, increasing freedom in mobility.

THE LEARNING PROCESS

Mobility is more challenging for the visually impaired. To become independently mobile, there are various assistive tools and training programs available, and mobility trainers can help assist in catering the learning process to an individual's needs. Mobility training begins with mastering basic skills. Learning the basis mobility skills prepares individuals for safe and effective movement, especially in traffic. This includes learning techniques with the cane, like the pendulum motion to detect obstacles and avoid collisions or the scrape and sweep technique to follow guide lines or locate curbs, and indoor movement techniques that do not require a cane, like hand-following and shielding, facilitate unassisted movement. Once on the move, one applies the acquired skills and strategies as required and often, a combination is used. (Royal Visio, 2021)

THE MOBILITY TRAINER

When individuals with visual impairments face mobility challenges, they can seek help from companies like Visio or Bartimeus, which provide services covered by insurance. A mobility trainer conducts an assessment of the client's orientation and mobility skills, problem-solving strategies, and sensory perception to identify their needs. They also evaluate the client's environment to determine how it affects their functioning and provide recommendations for improving mobility skills.

The primary objective is to equip the client for independence in society, enhance their mobility, and enable them to solve challenges autonomously. The mobility trainer assists the VIP in three key areas:

2. Person: This involves teaching skills, strategies, and understanding the environment.
3. Environment: Assessing and possibly modifying the physical environment is considered, along with educating and guiding the client's circle surroundings.
4. Activity: This involves adjusting the mode of transportation, altering routes, or introducing new aids.

TOOLS NEED TRAINING

All assistive tools, including seemingly simple ones like canes, need training. This project's solution will also require training, which is a familiar requirement for the visually impaired. When testing prototypes, it's essential to consider that users might need time to reach the full potential of mobility with the concept, possibly beyond the project's duration.

CONCEPTUAL UNDERSTANDING

OF THE WORLD

A conceptual understanding of the world, its objects, and spatial structures greatly aids mobility by allowing one to recognize and understand situations and predict the upcoming scenarios during movement. Public spaces are filled with these predictable patterns, and assisting in this conceptual understanding can enhance mobility. Spatial perception, which is central to this project's concept, is crucial for this conceptual grasp of spatial structures, highlighting one of it's potential key values.

GUIDELINES

One of the most important strategies in VI mobility is the guideline. Guidelines are paths through an environment that can be followed, often by following it with the white cane. There are different types of guidelines:

- Designated guidelines, often in the form of textured tiles on the ground that lead to bus stops, raised lines or braille signage. Such guidelines are typically found in public spaces such as sidewalks, transit stations, and public buildings
- Natural man-made guidelines: environmental elements that are not specifically designed for use by VIPs such as curbs, fences or building facades
- Natural guidelines formed by non-man-made elements in the environment such as hedges, edges of grass fields.

Designated guidelines help a lot in walking straightly and safely along the road, however, they may be easy to miss, especially at a faster pace. Therefore a VIP prefers the natural guideline: the hedge along the curb, the building facade along a busy road in the city, or whatever is present along the path that they can follow with the stick. This hedge or wall forms an easily traceable path for them to walk by. However, this natural guideline is sometimes blocked by unexpected elements such as bikes, dumpsters or shops, and it is less reliable and is often interrupted.

MENTAL MAPPING

CAPABILITY TO UNDERSTAND SPACE

The experience of a sighted person entering a space is markedly different from that of a visually impaired person (VIP). A sighted individual can immediately understand a room's size, layout, contents, and atmosphere. They can identify the people present, the furniture, and determine how to reach their destination, as noted by Royal Visio (2023). However, for a VIP, an unfamiliar space can seem vast and indeterminate. P1 compares this experience to the unknown vastness of the universe, expressing,

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

For VIPs, sound reflections are crucial in understanding a space. Unfortunately, these auditory cues can be compromised in environments with sound-absorbing materials like carpets and acoustic tiles or overwhelmed by background noise. These factors make spatial orientation a challenge, as outlined by Passini et al. (1986).

P2 highlights the difficulties in large public spaces such as hospitals, city halls, and public swimming pools, where poor acoustics and vast open areas without guide lines complicate orientation.

P2 notes: "You always orient yourself subconsciously through your hearing. If this channel is disturbed, for example, by a garbage truck or a truck making a lot of noise, you start walking askew because you lose your sense of where you are." This reliance on auditory cues and the challenges they face in certain environments underscore the distinct navigational experiences of VIPs.

THE NEED TO KNOW THE ENVIRONMENT

P5 discusses his proactive approach to understanding his environment: "If something changes, like a road being closed, I want to know how to navigate around it." His use of technology like Google Maps for localized information reflects a keen interest in his surroundings.

MENTAL MAPPING

Perception of the environment through the proximity senses occurs primarily up close, and the inability to form a comprehensive understanding of the surroundings from a single vantage point. Therefore, to form an overview of their surroundings, VIPs continuously interpret various sensory cues while moving around, mentally 'stitching them together' to form a spatial understanding of the environment. This process is called mental mapping. It is a structured process, in which the VIP must physically move around to explore an area. The addition of perceived environmental elements to the mental map is an ongoing process as the VIP navigates the environment. Mental mapping requires significant focus and memory recall. When a visually impaired person (VIP) is questioned about the cues they rely on for orientation and mobility, they would answer “everything” (Royal Visio, X). For instance, 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, 2014).

Mental mapping and self-orientation are strongly interdependent. Orientation is required to determine where and in which direction to add newly perceived information in the mental map. Orientation, in turn, relies on the mental map, through recognition and localisation of environmental elements or reference points.

Minor deviations in movement direction, e.g. because of a deviation in the path, often go unnoticed, which leads to inaccuracies in the orientation. This in turn leads to inaccurate mental maps of an environment (Papadoulos, 2020).

INFORMATION IN THE HEAD VERSUS INFORMATION IN THE ENVIRONMENT

Drawing on Donald Norman’s (1988) concepts of information processing, the distinction between how able-bodied individuals and visually impaired persons (VIPs) navigate their environments becomes quite clear. For those who are able-bodied, the majority of the information needed to navigate is readily available in the environment itself. Through vision, the spatial layout is easily accessed; the task of discerning this layout and choosing a route is largely ‘outsourced’ to the environment because of the constant visual feedback. This means that the cognitive load of mapping the environment is significantly reduced as the visual channel provides real-time updates and spatial cues.

In contrast, for a VIP, the lack of visual input means that this spatial information cannot be so easily acquired. None of the other senses naturally provide a comprehensive spatial mental image akin to that offered by sight. As a result, the conception of environmental representation must predominantly occur internally. This involves not only the construction of a mental map of the surrounding space but also simultaneous localization within this local mental map and a more abstract global map.

This internal processing is a remarkable feat, highlighting the intensive nature of mobility for VIPs. They must continuously gather, process, and update information through alternative sensory inputs like auditory, tactile, and olfactory cues. The mental effort required to construct and maintain these complex spatial representations, alongside the task of real-time navigation and obstacle avoidance, underscores the cognitive and sensory skills VIPs develop to achieve mobility and independence.

INCREASED PRESSURE ON MENTAL MAP

For blind individuals, without the benefit of sight, O&M is a more conscious process that heavily relies on the mental map, unlike sighted individuals who mainly rely on vision. If they lose orientation, they must actively search their mental map to match their perceived surroundings and identify their current location. Spatial problem-solving depends solely on this mental map, making the reliance on, and therefore the pressure on, the mental map much greater for VIPs than sighted individuals, making the mobility and orientation process more cognitively demanding. Most VIPs approach outdoor activities, especially in unfamiliar places, with focused intent rather than leisure (Brouwer et al. 2008).

UNDERSTANDING OF A ROUTE: LINEAR VS SPATIAL

To reduce complexity of a memorized route and reduce required memorization, it can be remembered as a series of landmarks (linear representation), as opposed to remembering the global map and route through that map (spatial understanding).

Spatial understanding is more flexible and allows the VIP to think of alternative routes, but requires much mental effort and memorization. Also, when the situation changes, the map has to be 'recompiled', which costs much mental effort. VIPs therefore apply different techniques for different routes, and ability to think in terms of spatial representation varies strongly per person.

RUIMTELIJKE VS LINEAIRE REPRESENTATIE VAN OMGEVINGEN EN ROUTES

Navigation environments are constantly evolving. Environmental changes can be temporal, like landmarks being obstructed by snow during winter. However, some changes are more permanent, such as new construction sites, relocation of bus stops, or familiar businesses closing down. Because the environment is constantly changing, the mental map must be constantly updated (Banovic et al.). Therefore, environmental changes are confusing and require a lot of energy from a VIP.

(P1): constant veranderende omgeving zorgt dat ik vaak de weg kwijtraak, en ik moet dan het beeld van de omgeving helemaal opnieuw maken.

Remembering an environment as a 3D mental map demands significant memorisation capacity, and updating this map when the environment changes is energy-intensive. An alternative to remembering a spatial representation of an environment is a linear representation of a route, which saves mental capacity by representing the route as a sequential set of landmarks. To navigate, one follows these landmarks in order, similar to the step-by-step instructions provided by navigation apps. While this strategy reduces the amount of information to remember, it has its drawbacks:

By only remembering the set of landmarks, more effort is needed to navigate between them. Without a spatial representation of the environment, one must pay closer attention to the environment while moving between these points. This strategy also lacks flexibility; if the known route becomes blocked for some reason, for example due to a roadblack, the linear understanding of the route does not readily allow the device of alternative paths. In such cases, a detour is needed, and if the detour does not rejoin the original route, an entirely route towards the end-goal must be found. Next to this, a spatial understanding doesn't enable traversing the area later with a different path or purpose.

Remembering environments and routes is

thus a trade-off between linear and spatial representation; here is a summary of the pros and cons for each strategy:

SPATIAL ENVIRONMENT REPRESENTATION

+ Provides overview and flexibility by being able to determine alternate routes/paths
+ While moving through an environment one can mentally look ahead and expect what is to come
- The larger amount of information takes more mental capacity and if an environment changes it takes more effort to adjust the mental map

LINEAR ROUTE REPRESENTATION

+ An easy an efficient way to remember routes
+ Allows more orientation between points
- Inflexible because no alternative routes can be devised and this form of understanding a place cannot be used later to cross surroundings through it in another way

ORIENTATION

Orientation is a crucial aspect of mobility, especially for visually impaired persons (VIPs). It involves understanding one's position, direction, and movement within an environment, relying on a detailed cognitive map and the perception and recognition of environmental elements.

Personal knowledge of the surroundings is vital in transforming observations into useful landmarks. Auditory cues, like the sound of a busy road or the scent from a bakery, can become navigational landmarks for a VIP. A participant highlighted using the sound of birds in an aviary near her workplace as a point of recognition. Such landmarks, combined with descriptions from companions, help in forming a mental map, enhancing the ease of movement in familiar environments (Royal Visio, 2022). A participant shared how she uses auditory landmarks for orientation:

"At the building where I work, there's an aviary with birds. It's a very good point of recognition. When I hear it, I know I'm close by." She also mentioned using these landmarks to navigate back: "When I walk with people, it helps if they describe the details around me. When I encounter them later, I know, 'Oh yes, I have to walk back this way.'"

Self-orientation encompasses an individual's understanding of their position, direction, and movement in a space. For broader-scale orientation, recognizing landmarks and meaningful elements is crucial. The precise localization of a landmark is less critical at this scale since it primarily aids in general navigation.

MOVEMENT

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).

Reference-based movement for VIPs involves using stationary landmarks as specific points for orientation, effective only until they are passed, at which point navigation becomes a guess. Landmarks can be thought of as zero-dimensional references for recognizing current locations.

Navigating between two points involves determining direction and distance traveled, a challenge without perceiving the environment's movement relative to oneself. Maintaining direction requires the use of a cane or following rectilinear environmental features like footpath edges or fences. People with residual vision use similar strategies, perceiving them visually when possible.

> *"In order to maintain a wayfinding direction, totally blind travelers will rely on the cane if they do not have a dog guide and will use any rectilinear feature in the environment, such as the edge of a footpath, a wall, or a fence. Sometimes, they can follow the movement of other people or even motor traffic. People with visual residue utilize similar information but perceive it visually when possible." (Passini et al., 1986)*

Two strategies for blind navigation include (1) using a guide line as a continuous stream of reference points, and (2) following a crowd, another form of perceptible reference. These methods, similar to those used by sighted individuals, are based on proximity senses. However, they are inflexible as they follow a set path or crowd direction, often not directly towards the destination.

VIPs often prefer environments with objects and boundaries as references over open spaces with fewer paths. In open spaces, orientation can be more challenging due to the lack of landmarks and guide lines, as explained by a participant who struggles with diverging from the intended path in such environments.

VIPs therefore prefer a place where they have objects and boundaries as reference over a large open space, which contains fewer paths.

P1: "In large open spaces, I can veer off and then lose my way because I might hear an exit that's actually the wrong one, or find a guide line that leads to the wrong exit. A large open space is difficult because there are 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.

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.

MENTAL SCALE

For mobility, a VIP needs to remember many routes and places, which involves a lot of information. For different mental scales, different information is relevant. To be able to memorize and 'view' the mental map more efficiently, a lot of this information can be abstracted away based on the purpose and mental scale: if one needs to know the overall route and which street to take, the exact locations of poles or bicycles on the path aren't relevant. Onh the other hand, when moving through a tight space along the curb, the overall environment and street layout are less relevant. Depending on the situation and focus, one can shift between levels of abstraction or detail. Mental scale is essential to manage the vast amount of information effectively because of the limited capacity to memorize and represent the large amount of information in day-to-day environments.

Variations on mental scale in literature

Hersh & Johnson, identify two scales: near space and far space. Near space refers to "the space immediately around the person's body", while far space refers to "the distant geographical space". (Hersh & Johnson, 2008)

Katz uses these same concepts, however he/she calls them micro- and macro navigation, respectively. (Katz et al., 2012).

In these models, mental scale is discribed as discrete, identifying two different scales. While this binary distinction often suffices for basic explanations, it fails to acknowledge the crucial aspect of mental scaling that it is a continuous spectrum. One can conceptualize an environment or route on countless scales, each with its unique elements. Processes across various scales interact with each other.

Oversimplifying this continuous scale would imply that one can think about an environment in a set number of distinct scales. However, it's essential to recognize that mental scaling is more intricate, and its variations can be infinite based on context.

APPENDIX D EXPERIENCE AND TARGET GROUPS

The intricacies of mobility, particularly for visually impaired people (VIPs), encompass far more than mere physical movement. This study delves into the profound psychosocial aspects of mobility, uncovering the personal, emotional, and experiential dimensions that profoundly influence the lives of VIPs. Our goal is to present a detailed and empathetic understanding of how visual impairment affects mobility, and in turn, how these mobility challenges impact the psychological and social well-being of individuals.

Through in-depth interviews, field research, and a comprehensive review of existing literature, this research seeks to capture a broad spectrum of experiences and perspectives. This multidimensional approach provides a holistic picture of the mobility experience for VIPs, highlighting not only the challenges but also the resilience and adaptability that characterize their daily lives.

This research aims to provide valuable insights for a range of stakeholders, including mobility trainers, healthcare professionals, urban planners, and technology developers.

MOBILITY: BEYOND PHYSICAL MOVEMENT

Mobility for VIPs transcends the basic act of moving from one place to another. It is a cornerstone of independence, self-worth, and societal participation. As Marston and Golledge (2003) insightfully observe, mobility is not just a physical phenomenon but a self-defining one, deeply intertwined with an individual's sense of identity and place in society.

Independence and Self-Worth

The ability to move independently is pivotal in shaping a VIP's self-concept. Many participants expressed feelings of isolation and exclusion when they could not participate in activities like driving, which their peers took for granted. For instance, P6's lament, "When all your friends can get their driver's license and go places, and you cannot," poignantly highlights this sense of isolation. Such experiences are not merely about the inability to perform a task but reflect deeper issues of autonomy and belonging.

Societal Participation

Mobility also plays a crucial role in societal engagement. The lack of independent travel options can lead to significant psychological impacts, such as feelings of inequality and depression. Participant P7's struggles with public transport, where the fast-paced environment added layers of complexity to their experience, exemplify this challenge. Their narrative underscores how mobility restrictions can limit participation in societal life, reinforcing feelings of marginalization.

The Emotional Landscape of Mobility

The emotional impact of mobility, or the lack thereof, manifests in various forms. It can be a source of empowerment when achieved, or a cause of distress when hindered. Our study found that the emotional landscape of mobility is complex and deeply personal. Each individual's experience is shaped by their unique circumstances, yet certain themes, such as the desire for independence and the pain of exclusion, are universally resonant among VIPs.

Conclusion

In understanding the personal significance of mobility, it becomes clear that it is more than a functional necessity; it is a fundamental component of identity and societal participation. This recognition is important for a more empathetic and comprehensive approach to addressing the mobility needs of VIPs, an approach that acknowledges the full spectrum of their experiences and aspirations.

SOCIAL EFFECTS

2.1 SELF-CONFIDENCE AND SOCIAL DEPENDENCE

For VIPs, self-confidence is crucial for independent travel and is significantly influenced by social interactions. Jolanda's story of gaining self-confidence through living alone after a relationship breakdown illustrates how independence is intertwined with social acceptance. Beyond personal achievement, independence in VIPs is a key factor in societal acceptance. However, societal attitudes can undermine VIPs' self-confidence. Research suggests that VIPs often feel more impaired by social attitudes than their actual visual impairment. Their self-consciousness and critical view of their public appearance can be exacerbated by society's failure to recognize their spatial abilities or achievements. Even well-intentioned actions can sometimes reinforce feelings of incompetence.

While the spatial capabilities of visually impaired people (VIPs) are essential in understanding their mobility, research indicates that societal attitudes often pose a more significant barrier than the physical impairment itself. Reeve (2005) notes that VIPs frequently feel more 'disabled' by the social responses to their condition rather than by the impairment itself. This societal perspective can lead to feelings of marginalization and powerlessness, challenging the VIPs' ability to navigate public spaces effectively.

Moreover, VIPs tend to be highly self-conscious and critical of their public appearance and behavior, as observed by Butler and Bowlby (1997). This heightened self-awareness can stem from the perceived and experienced attitudes of others, further complicating their interactions and mobility in public spaces.

Pow (2000, p. 176) adds to this discussion by examining the social dimension of public space for the visually impaired. According to Pow, the societal perceptions and limitations imposed on disabled bodies can significantly restrict the spatial efficacy of VIPs. However, Pow also points out that these notions of marginality and powerlessness are continually being challenged, suggesting a dynamic and evolving interaction between VIPs and the social environment.

Worth (2013) adds another layer to this discussion, highlighting that the achievement of greater mobility and independence in VIPs is often undermined by societal failure to recognize these accomplishments. The societal tendency to view VIPs as in need of help or as subjects of ridicule can dampen their attempts at becoming competent spatial actors. The challenge often lies not in navigating the city but in confronting public scrutiny and judgment. This societal judgment can impede young VIPs from feeling competent and damage their self-image.

When P3 moved to Soesterberg and ended her relationship, she discovered her capability to live independently. This realization significantly boosted her self-confidence. She reflects, "Gaining confidence brought me freedom; I started going out, enjoying life, and meeting people in Soesterberg who I connected with. This made a huge difference for me."

THE IMPACT ON A SOCIAL LIFE

CHALLENGES IN MAINTAINING FRIENDSHIPS

VIPs frequently face the fear of losing friends due to their inability to participate in shared activities. P6's experience is a testament to this struggle. He recalls, "We used to go to the football club to play ball with the boys. I could not do that anymore, so I lost friends out of sight," and, "also watching football was not possible anymore." The need to find new friends becomes a reality for many VIPs when their impairment starts impeding important social activities.

THE UNIQUE SITUATION OF YOUNG VIPS

For young VI children, especially those placed outside their parental home for more comprehensive care, the challenge of maintaining friendships is even greater. As P3 Fijneman notes, "You lose [friends] out of sight, because you're never at home during the week anymore." This displacement often results in the loss of childhood friendships and can lead to feelings of isolation.

THE SOCIAL FUNCTION OF CO-TRAVEL

The role of co-travel in the lives of VIPs is significant. Navigating and engaging with the city is not just a physical task but a 'networked, relational, and social' activity. Worth (2013) highlights that reliance on social groups for help and shared activities is intrinsic to the concept of autonomy for VIPs. This dependence on others for navigation and social interaction shouldn't be viewed negatively but rather as an integral aspect of VIPs' independent mobility.

Middleton et al. (2019) emphasize the importance of social interaction during mobility for VIPs. Devices or aids designed to assist VIPs in travel should ideally facilitate these social interactions. As P7 aptly puts it, "Traveling together has a social function that should not be taken away."

SOCIALE SCHAAMTE, FEAR OF STIGMA AND EMBARRASSMENT

THE CHALLENGE OF SOCIAL SHAME AND SEEKING ASSISTANCE

Many VIPs experience social shame related to their condition, leading them to resist seeking help or to conceal their mobility aids. This coping mechanism, aimed at fitting in with societal norms and avoiding stigma, can negatively impact their self-esteem and independence. As P1 states, “I’m just a normal guy. I just have a larger challenge when I move around.” This sentiment is echoed by mobility trainer Jolanda Kremer, who emphasizes that VIPs yearn to be normal, follow their role-models and not be ostracized from social groups.

RESISTANCE TO ASSISTANCE AND INDEPENDENCE

VIPs often resist assistance to maintain their independence. P6 Smits shares, “In the weekends when I went home, I used to fold my cane and put it in my inner pocket,” illustrating the lengths some go to hide their impairment. Another participant, P7, expresses a preference for self-reliance: “I don’t ask for help unless it’s too exhausting. You can only spend your energy once.”

COPING WITH ENVIRONMENTAL CHALLENGES

The unpredictability of environmental circumstances, such as traffic, exacerbates feelings of insecurity among VIPs. Dependence on others can be difficult to accept, often leading to a fear of getting lost or appearing incompetent. P10 candidly shares, “I have already had the experience where I couldn’t find my own home. I felt like a fool.”

Coping Strategies Among Young VIPs

Young VIPs, especially those in non-VI schools, face unique challenges, often leading to exclusion by peers. They tend to employ various coping strategies to blend in and feel worthy. These include concealing their impairment and downplaying their reliance on assistance. Overprotection by friends can sometimes lead to disempowerment, as noted by Seybold (2005).

Independence as a Social Tool

Independence becomes a significant factor in social acceptance for VIPs. The risk of unequal relationships and the fear of burdening others can lead to internal conflicts, harming familial and friendly relationships. For instance, P1 often chooses to walk with friends to avoid burdening them, and P6 prefers to be independent at social gatherings.

Evolution of Coping Strategies with Age

Coping strategies and the pursuit of self-worth evolve as VIPs age. Initially, young VIPs might try to hide their disability, especially when they start attending new schools and seek independence. However, as they transition to adulthood, their focus shifts towards enhancing their mobility skills and gaining competence. For instance, acquiring a guide dog is often seen as a sign of maturity and adulthood, as it implies mastering complex routes and caring for the animal, thereby increasing social interaction and independence.

SELF-ACCEPTANCE AND ACCEPTANCE OF THE CONDITION

COPING WITH NEW OR INCREASING VI

Adjusting to new or worsening VI can be a challenging and frustrating experience. Difficulties in coping with impairment lead to feelings of fear and frustration, which result in resistance towards seeking help and adopting tools. (Brouwer, 2008). This resistance can manifest in different ways, including avoiding mobility to escape facing their condition, and denial of their situation during mobility, which triggers negative feelings.

THE NEED FOR POSITIVE SELF-CONCEPT

For successful adjustment to and acceptance of one's disability, a positive self-concept is crucial. This encompasses beliefs, feelings, and ideas towards oneself. Seybold (2005) emphasizes that psychosocial factors play a significant role in how VIPs deal with their new situation. Often, becoming blind involves dealing with strong psychological effects such as insecurity, denial, and concealment of the disability.

THE DOWNWARD SPIRAL OF AVOIDANCE

Difficulties in coping with impairment often lead to a downward spiral where fear and frustration result in further resistance to seeking help and adopting necessary tools. This resistance negatively impacts the VIPs' ability to adjust to their new situation. Environmental factors, such as traffic, can exacerbate feelings of insecurity and dependency, as highlighted by one participant who shared, "I have already had the experience I couldn't find my own home. I felt like a fool."

THE IMPORTANCE OF POSITIVE FEEDBACK

A lack of motivation and confidence to adapt to vision loss can lead to withdrawal, depression, and avoidance of mobility. Fear of dangers in unknown environments may cause VIPs to restrict themselves to familiar surroundings, further fueling frustration and negative emotions. However, the ability to perform tasks can create satisfaction. As such, exposure to mobility challenges and receiving positive feedback during these activities are essential for building the motivation and self-confidence needed to regain competence in spatial navigation.

FEAR AND CONTROL

THE DIFFICULT TASK OF NAVIGATION

Navigation for visually impaired persons (VIPs) is a complex, attention-demanding task, requiring continuous self-orientation and mental mapping. Even experienced individuals find it challenging to understand their environment and navigate it. P1 reflects on the change in his walking habits due to visual impairment: “Before, walking was almost like sprinting. Now, I must walk slowly to avoid bumping into things.” P3 adds: “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, you know, I couldn’t get back to the building. You know, so one time someone said, What are you doing? I say, I’m looking for directions, you know? Oh yeah, You have to walk all this way, you know. And and and then sometimes it’s kind of like a maze and and and and and yeah, there there yeah, I do fear that sometimes you’re walking the wrong way then yeah.”

Accidents can exacerbate the fear of navigating independently. P3’s experience of falling from a train platform led to a temporary avoidance of solo travel. P7 speaks about the fear of getting lost or stuck, recounting an incident of being trapped behind a fence and feeling like in a maze.

Loud environments pose additional challenges for VIPs. They rely on echolocation for positioning, which gets disrupted in noisy settings. P3 notes, “You also orient yourself using hearing. If disrupted, like by loud vehicles, you can lose track of your position.” Regular changes in environments, such as train or bus stations, further complicate navigation. P5 discusses the difficulties posed by inconsiderate people and traffic, longing for more certainty for peace of mind.

The lack of clarity and foresight in their surroundings often leaves VIPs in a state of constant vigilance, concerned about overlooking dangers. This uncertainty persists even on familiar routes, where unexpected obstacles like obstructed guiding lines can emerge. Consequently, their mobility is often accompanied by stress and a need for self-efficacy.

A lack of spatial overview and the difficulty in orientation and path preview limit VIPs in their freedom and lead to disengagement from their environment. P5 explains his need for spatial overview and awareness of hazards: “When I walk in the city center, there are trees, cars along the canal. But here, there’s nothing like poles or railings. It’s just an open area where you could easily walk into...” P1 emphasizes the desire for efficiency and ease in navigation: “Ultimately, you want to move more efficiently and quickly. Better spatial insight is what you need to achieve that.”

For VIPs, rushing is not an option. They operate within a different time frame, needing to maintain a careful, consistent pace. This necessity restricts their ability to move spontaneously or on autopilot. Some respond to these challenges with over-preparation and intense focus during walks, further reducing the spontaneity of their mobility.

Fear profoundly impacts the mobility of VIPs. According to Beggs’ 1992 study, fear of danger, lost control, and the need for vigilance dominate their emotional landscape during navigation. P1's experience epitomizes this, having to significantly slow down his walking pace due to fear of bumping into things. P3's and P7's experiences highlight the real dangers and psychological impact of getting lost or stuck, emphasizing the multifaceted challenges VIPs face in navigation.

THE RESULTING HYPERFOCUS AND VIGILANT STATE OF MIND

VIPs often enter a state of hyperfocus and vigilance due to the constant demands of navigation. This heightened state stems from a fear of disorientation and the subsequent challenge of reorienting themselves. P7 emphasizes this concern: "My biggest fear is getting lost or stuck. I prefer sticking to known routes and prepare thoroughly to avoid this."

The fear of missing hazards due to reduced overview is a significant concern. P5 notes the unpredictability of the path: "You don't know what's coming; you could end up in a ditch." This reduced foresight often leads to frustration and overcompensation, as P7 explains: "Unforeseen circumstances drain energy. You're frustrated: 'Why is there a car on the guiding line?' But if you know about it 10 meters ahead, it's just a car."

The difficulty in recognizing surroundings intensifies the fear of losing orientation. P7 prepares extensively and takes earlier buses to manage this anxiety, sacrificing significant time. P5 and P1 also reflect on how busy environments or those with more obstacles increase the likelihood of missing something and feeling less relaxed. P5 expresses a desire for devices that indicate relevant dangers, like a nearby canal, which would reduce uncertainty.

This intense focus on the direct path and orientation leads to high emotional strain. VIPs become dependent on over-preparation or familiar routes to mitigate the risks of unknown dangers. Their vigilance, driven by fear of accidents, intensely concentrates their attention on their route, potentially leading to avoidance behavior and a narrowing of their living environment.

This results in a strong focus on the direct path to avoid dangers, and on the orientation, to avoid losing the way. This in turn results in high emotional strain and a dependency on over-preparation or sticking to familiar routes to avoid unknown dangers. VIPs' vigilance in mobility, driven by fear of accidents, focuses their attention intensely on their route. This mental effort can lead to avoidance behavior and a shrinking of their living world, as they cling to known routes.

OVERPREPARATION AND RELUCTANCE TO EXPLORE NEW ROUTES

For VIPs, extensive preparation is essential for ensuring safety and reducing mental strain. This preparation involves familiarizing themselves with landmarks, understanding potential obstacles, and anticipating route changes. P7 highlights this, expressing his desire to know safe routes and his tendency to explore new routes with someone to feel secure. He admits to being a meticulous planner to avoid errors, contrasting with those who adopt a more relaxed approach.

Learning new routes is a demanding process for VIPs, requiring significant energy and mental effort. P7 elaborates, “Taking a new route means you have to learn it, which costs a lot of energy. The more familiar you are with the route, the less energy it takes, but that requires initial energy investment.” This need for extensive preparation leads to reduced spontaneity and flexibility in mobility, often resulting in monotony.

P5 notes the boredom associated with repeatedly walking the same routes and makes efforts to train himself and his guide dog on different paths to avoid this monotony. Yet, P7’s comment, “Het leven wordt iets geplander” (Life becomes more planned), encapsulates the loss of spontaneity VIPs often experience, hesitant to embark on impromptu trips due to the uncertainty they bring.

Middleton (2011) contrasts this with non-VIP urban commuters, who often describe their routine travels as autopilot experiences, paying little attention to their surroundings. VIPs, conversely, cannot afford this luxury due to the continuous attention and vigilance required in urban commuting with assistive technologies.

The challenges and heightened vigilance in unfamiliar environments often lead VIPs to avoid new places. As Brouwer (2008) observes, sticking to familiar routes reduces encounters with unexpected obstacles but also limits spatial overview and confidence in exploring new areas, potentially leading to social isolation.

P7 wishes for a more flexible mindset, envisioning scenarios where he could adapt more spontaneously to changes in travel plans. Yet, he acknowledges his tendency to over-plan to ensure nothing goes wrong.

Additionally, this vigilant state of mind impacts VIPs’ ability to engage with their environment. Their environmental perception and interaction become purely functional. P1 focuses primarily on the current path, while P5, despite knowing his regular walking route well, laments his lack of awareness of his surroundings, such as the appearance of houses or front doors.

In conclusion, the necessity of extensive preparation for VIPs, while crucial for safety, often leads to a reluctance to explore new routes, a reduction in flexibility and spontaneity in their daily lives, and a more functional than engaging interaction with their environment.

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.

THE FUNCTIONAL NATURE OF ENVIRONMENTAL INTERACTION

The functional nature of environmental interaction for visually impaired persons (VIPs) stems from their lack of confidence and a vigilant state of mind, often leading to a disengagement from their surroundings. Their interaction with the environment is primarily focused on practicality and safety. P1 notes, “When walking, it’s mainly the current path and direction that are important.” P5 adds, “I know where I am because I frequently walk here with my dog, but I don’t know what the houses look like. I miss knowing things like the types of roofs or front gardens people have.”

Despite these constraints, VIPs’ curiosity about their surroundings persists. P5, for instance, expresses a desire to know more about his environment, such as the details of people’s front doors. He actively explores with his wife to gain a better understanding of the places he frequents. P1 emphasizes the importance of knowing what a street looks like in preparation for navigation.

For children with congenital blindness, the challenges in understanding and being curious about the environment are even more pronounced. Without visual stimuli, forming concepts like leaves or trees can be difficult, leading to a more utilitarian perception of the environment.

VIPs operate on a different temporal rhythm, taking their time to navigate and preferring not to be rushed, as highlighted by Middleton (2019). This slower pace is reflective of a need for careful planning and attention to surroundings. Reducing anxiety and embarrassment can involve focusing on the task at hand, which might encourage greater environmental presence and less self-consciousness.

Exploration for VIPs is less about curiosity-driven exploration and more about achieving specific goals, as illustrated by P1 and P3, who focus mainly on essential information for navigation.

REDUCING THE STATE OF MIND THROUGH CONFIDENCE AND OVERVIEW

Improving spatial overview and orientation can significantly enhance VIPs' freedom and engagement with their environment. P5's need for spatial awareness in different settings, such as the city center versus open areas, highlights this. Similarly, P1 emphasizes the desire for more efficient and confident navigation: "Ultimately, you want to move more efficiently and quickly. Better spatial insight is what you need to achieve that."

The vigilant state of mind that restricts VIPs stems from a lack of spatial overview, leading to a reliance on familiar routes and potential isolation from the community, as noted by Brouwer (2008). P1's avoidance of new routes and P7's wish for a more flexible mindset underscore the impact of this limited overview on their confidence and willingness to explore new areas.

In summary, the functional nature of VIPs' environmental interaction is a result of their vigilant state of mind and limited spatial overview. Enhancing these aspects can lead to a reduction in the reliance on familiar routes and promote a more engaged and confident exploration of their environment.

TARGET GROUPS AND PERSONA DEVELOPMENT

In the realm of mobility for visually impaired persons (VIPs), understanding the diversity within the target groups is crucial. This section focuses on the development of personas based on extensive research, including interviews and collaborations with mobility experts from Royal Visio. These personas are not mere fictional characters but represent real-life complexities and diversity within the VIP community. They serve as tools for empathetic design, guiding the development of solutions tailored to specific needs and experiences.

The development of the personas was based on:

1. Interviews and Field Research: Direct input from VIPs was gathered, providing insights into their daily mobility challenges, coping strategies, and aspirations.
2. Collaboration with Experts: Mobility trainers and experts from Royal Visio offered professional perspectives on the diverse needs and abilities within the VIP community.
3. Data Analysis: Information from interviews and expert inputs was analyzed to identify common patterns, needs, and challenges.

By understanding the varied experiences and needs of VIPs, we can create solutions that are truly user-centric, addressing the unique challenges faced by each subgroup within the broader VIP community. These personas serve as a reminder that behind every design challenge, there are real people with real stories, hopes, and needs. Based on this research, several key personas emerged, each representing a distinct subset of the VIP community:

1. **Learning Child**
    - Young VIPs learning mobility and conceptual understanding of the world.
    - Limited self-motivation to actively explore outside.
    - Challenges in grasping spatial concepts and forming world concepts.
    - Identity formation is a significant aspect at this stage.
2. **Functionally Mobile**
    - The working/active group regularly venturing outdoors.
    - Proficient in basic skills like orientation and navigating with a cane or phone.
    - Past the stage of mobility training, relying on personal motivation for further skill enhancement.
    - Often encounters unfamiliar environments, leading to high energy consumption and vigilance.

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    - Past the stage of mobility training, relying on personal motivation for further skill enhancement.
    - Often encounters unfamiliar environments, leading to high energy consumption and vigilance.
3. **Curious Pro**
    - Highly skilled and motivated, blind from a young age.
    - Excellent mastery of basic mobility skills.
    - Driven by curiosity and a desire to improve, often exploring new tools and methods for better mobility.
4. **Young & Adapting to Growing Impairment**
    - Dealing with a growing impairment and adjusting to the situation.
    - Resistance against using tools and accepting help, viewed as conceding to their condition.
5. **Homebound Middle-Lifer**
    - Struggling with growing or unaccustomed impairment.
    - Experiencing a spiral of seclusion, fear, and shrinking social circles.
    - Reluctant to depend on others, fearing a change in relationships and friend dynamics.
6. **Homebound Elder**
    - Little motivation to venture outdoors due to diminished social circles and mobility skills.
    - Risk of confinement countered by maintaining independence.

THE CURIOUS PRO

CHARACTERISTICS

The Curious Pro persona is characterized by individuals who have been visually impaired from a young age and have developed an exceptional mastery of mobility skills. They are highly skilled, motivated, and often involved in activities that challenge their mobility capabilities. This group is characterized by their curiosity and desire to constantly improve and explore. They are often early adopters of new technologies and methodologies in mobility and are proactive in seeking out and experimenting with new solutions..

CHALLENGES

The challenges faced by the Curious Pro are primarily related to their desire for continuous improvement and exploration. They often seek out new environments and experiences, which can present unique navigation challenges. Their high skill level means that they are frequently pushing the boundaries of what is possible with current mobility aids and techniques, leading them to encounter limitations in existing technologies. Additionally, their adventurous spirit might sometimes put them at odds with societal norms or expectations, creating social challenges.

NEEDS

The Curious Pro needs advanced, cutting-edge mobility tools that can keep pace with their desire for exploration and improvement. They require technologies that provide detailed environmental feedback and allow for efficient and safe navigation in complex and dynamic settings. There is also a need for a supportive community that understands and appreciates their drive for continuous improvement. Access to platforms where they can share experiences, learn from others, and contribute to the development of new mobility solutions is also important for this group.

FUNCTIONALLY MOBILE

CHARACTERISTICS

The Functionally Mobile persona represents adults who have adapted to their visual impairment and have developed a proficiency in basic mobility skills. This group typically includes individuals who have either been visually impaired from a young age or have had sufficient time to adjust to their impairment. They are often engaged in daily activities such as work or community involvement and exhibit a degree of independence in their mobility. These individuals are familiar with and capable of using various assistive tools and techniques, such as white canes or navigation apps on smartphones.

CHALLENGES

Despite their proficiency in basic mobility skills, the Functionally Mobile face challenges, particularly in unfamiliar environments. Navigating new places can be energy-intensive and stressful due to the heightened need for vigilance and the potential for unexpected obstacles. These individuals may also encounter social barriers, such as societal attitudes or physical environments that are not accommodating of their needs. The balance between seeking assistance and maintaining independence is a constant negotiation, often influenced by the environment and the tasks at hand.

NEEDS

The primary need of the Functionally Mobile is to reduce the mental and physical strain associated with navigating unfamiliar settings. This includes having access to reliable and intuitive navigation tools that provide real-time information about their environment. Enhancements in assistive technology that offer more detailed environmental data can significantly aid their navigation. Additionally, there is a need for societal awareness and inclusive design in public spaces to reduce the barriers they face. Support systems, both professional and personal, that respect their independence while providing assistance when needed, are also crucial.

LEARNING CHILD

CHARACTERISTICS

The Learning Child persona encapsulates young visually impaired individuals who are at the initial stages of understanding and navigating the world around them. This group is characterized by their youthful curiosity and their ongoing development in both cognitive and motor skills. They are in a phase where the world is a blend of exploration and education, with each experience playing a crucial role in shaping their perception of their surroundings. Typically, these children are in a structured learning environment, either at home or in specialized institutions, where they are beginning to form their fundamental concepts of space, distance, and orientation.

CHALLENGES

One of the primary challenges faced by the Learning Child is the development of spatial awareness and mobility skills without the benefit of visual cues. They often struggle to grasp abstract concepts like distance, direction, and spatial relationships, which are more easily understood by their sighted peers through visual observation. The absence of visual learning means that these children require more tactile and auditory experiences to build a mental map of their environment. Another challenge is the social aspect of their development; they might feel isolated or different from their peers, which can impact their self-esteem and willingness to engage in new experiences.

NEEDS

The needs of the Learning Child are multifaceted, focusing on both educational and emotional aspects. They require tailored mobility training that goes beyond basic cane skills, encompassing a comprehensive approach to understanding their environment through other senses. Interactive and engaging learning tools that stimulate auditory and tactile senses are vital for their spatial understanding. Moreover, these children need a supportive social environment that fosters confidence and a sense of belonging. Encouraging their independence in safe and controlled settings can significantly contribute to their self-esteem and willingness to explore. Emotional support from family, educators, and peers is essential in helping them navigate the psychological aspects of their visual impairment.

YOUNG & ADAPTING TO GROWING IMPAIRMENT

CHARACTERISTICS

This persona represents young individuals who are experiencing a recent increase in visual impairment. They are in a transitional phase, adapting to a significant change in their sensory experience and mobility. These individuals are often grappling with the emotional and practical implications of their changing condition. They may have had a degree of visual independence previously and are now facing the challenge of relearning or adapting their mobility skills.

CHALLENGES

The primary challenge for this group is the internal conflict between acknowledging their changing needs and resisting the adoption of new mobility aids or assistance. This resistance often stems from a fear of stigma and a reluctance to appear vulnerable or dependent. They may also face practical challenges in learning new mobility skills and incorporating them into their daily routines. Emotionally, this period can be fraught with frustration, denial, and a sense of loss.

NEEDS

The needs of this group center around support for adaptation and acceptance. They require patient and empathetic guidance in learning new mobility skills and adapting to their changing situation. Emotional support is crucial, as is the availability of counseling or peer support groups. They also need access to mobility aids and technologies that are easy to learn and use, helping to bridge the gap as they develop new skills. Societal understanding and the de-stigmatization of visual impairment and mobility aids are also important to help them navigate this transition with confidence.

HOMEBOUND MIDDLE-LIFER AND ELDER

CHARACTERISTICS

This persona includes middle-aged and elderly individuals who are experiencing a decline in mobility skills due to aging or a progressive visual impairment. They may have been independent in the past but now find themselves increasingly homebound. This group often faces a combination of visual and other age-related impairments, which further complicate their mobility and daily living activities. Their world may be shrinking as they become less able to engage in activities outside their home.

CHALLENGES

The main challenge for the Homebound Middle-Lifer and Elder is the spiral of seclusion and declining mobility skills. As they venture out less, their skills and confidence in navigating the outside world diminish, leading to further withdrawal. This can result in social isolation and a significant impact on their mental health. They may also face practical challenges in accessing necessary services and participating in community life.

NEEDS

Their needs center around maintaining independence to counteract the risk of confinement. Tools and strategies that enable safe and independent navigation within and outside the home are vital.

APPENDIX E EXISTING ASSISTIVE SOLUTIONS

This research aims to delve into the complexities and emerging trends in this sector, focusing on how changes in market behavior, technological advancements, and user expectations are reshaping the way assistive devices are developed, marketed, and utilized. This research is based on:

- interviews with 6 experience experts from different areas of the market who are experts in (high-tech) assistive technology for people with visual impairments.
  They are kept anonymous so as not to complicate their opinions about certain products or companies. The analysis is my interpretation of their view of the market.
- Literature on (models for) tools, benchmark analyses, and Internet research on tools

GENERAL MARKET INSIGHTS

The research yields several general insights in the market of assistive technologies for VIPs;:

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).

This shift towards direct consumer purchase indicates that future users might buy products themselves instead of receiving them through professional prescriptions, impacting product marketing strategies and pricing. Marketing efforts should now be more user-centric, focusing directly on end-users.

TRUST CALIBRATION AND EXPECTATION MANAGEMENT AND THE DESIGNED LEARNING PROCESS

Many products promise significant mobility improvements. However, achieving these benefits usually depends on the user's proficiency with the tool, which requires adequate training. Often, the importance of this training process is not mentioned by the manufacturer or inadequately supported. Users start using the product with high expectations, but without sufficient opportunity to familiarize themselves with it, these expectations frequently remain unfulfilled. This leads to disappointment and a sense of distrust in the tool, which does not manage to live up to the expectations. This causes many potentially beneficial products to end up unused and forgotten. it is unfortunate because these products often have greater potential than realized (Mark Lanting).

A better example is the BiPed's gamified learning curve, in which users 'unlock' functions by completing achievements, ensuring they are exposed to complex features only after mastering basic ones. This makes learning enjoyable and engaging, motivating users to practice and improve (P3 Wienholts).

While the BiPed is still in development and its long-term effectiveness is unconfirmed, this gamified learning curve forms a compelling approach for this project, which could greatly enhance user engagement and proficiency, help build user trust and make the learning process more enjoyable and effective and aligns with designing products that are not only functional but also user-centric and engaging. Given the conceptual nature of the project, incorporating a thoughtful learning curve is a key recommendation for future development.

An interesting example of a more thoughtful approach is the BiPed. With this product, not just the product itself has been designed, but also the learning curve: The learning process of engaging with the system is 'gamified', allowing the user to "unlock" various functions by achieving specific "achievements". In essence, the product 'obliges' a step-by-step learning process and embodies the idea that more complex features should only be accessed when the user is ready and familiar with the system's fundamental principles. Additionally, it encourages practice as completing specific exercises leads to rewards, turning the learning process into a fun activity rather than a source of frustration. It's essential to note that the BiPed is still in its developmental phase, and long-term results are not yet known. However, I find the underlying philosophy intriguing and relevant to the project.

A clear and well thought-out learning curve is essential for managing expectations, calibrating trust, and ensuring a successful and enjoyable learning process. By adopting a step-by-step approach, individuals can progressively build confidence with the tool, ensuring both the user and the tool synchronize in their capabilities and functions. This not only enhances the user's experience but also maximizes the tool's effectiveness.

THE NEED FOR INTEGRATED SOLUTIONS

Mainstream technology such as smartphones has largely replaced the need for carrying multiple 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.

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 topics 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.

CHALLENGES OF SENSORY OVERLOAD AND HANDS-FREE USE

Mobility is an energy-intensive activity requiring the processing of much information simultaneously. Many products that attempt to increase environmental awareness can overload the user's senses. Mobility products should be efficient and allow for hands-free operation. Wearable haptics are an example of products designed for hands-free use, enabling simultaneous use with other tools like a white cane. However, these often have low bandwidth, conveying limited information and requiring a specific language to be learned.

Avoid the experience of a ‘black box’ (because of AI)

To overcome sensory overlap, research is focusing on algorithms, increasingly using AI, to filter and tailor information. However, such technology can lead to distrust if users feel they are not getting a complete picture of the environment. Products that filter information too strongly can be perceived as unreliable ‘black boxes’.

TRADITIONAL ASSISTIVE SOLUTIONS

The most popular and well-known tools are the white cane and the guide dog. These tools are familiar, simple and well-supported by easily-accessible training, e.g. by Bartimeus and Royal Visio.

WHITE CANE

The primary tool for VIPs is the white cane, distinguished by its white color with often red details. There are two types: the signalling cane for visibility and the long cane for navigation. The long cane, widely used globally, acts as a tactile extension, helping VIPs detect obstacles and understand ground textures. It functions as an extension of one's tactile sense: It allows the user to 'feel' their environment from further away and enables VIPs to detect obstacles, and provides rich information by letting the user feel the texture of the ground.

SIGNALLING FUNCTION

The white cane's key function is to signal a VIP's disability to others, so vital that insurance often requires it for solo travel. If future technology replaces the cane, this signalling role must be retained. This visibility not only ensures safety but also enhances the VIP's experience: sighted individuals often assist by clearing paths, giving directions, and offering convenient seating. Thus, mobility is improved by both the cane and considerate actions of others.

WALKING TECHNIQUE WITH A LONG CANE

Using a long cane requires a bit of technique for effective mobility. The cane should be swept from side to side, roughly in alignment with the user's shoulder width. This ensures a comprehensive scan of the surrounding area, minimising the chances of encountering unanticipated obstacles. It is crucial to maintain a high pace while swinging the cane; a slow sweep could result in missing critical changes in the terrain, such as an upcoming turn. It is common to experience some arm fatigue when first learning to use a long cane. However, adopting a relaxed grip can alleviate muscle strain, making it possible to cover greater distances without discomfort. The white cane also helps orientation through sound: VIPs can quite accurately determine their distance to space boundaries based on the reflection of the sound of the ticking of their cane.

GUIDE DOG

Guide dogs, also known as service dogs, are trained to assist people who are blind or visually impaired by walking together with them. They are carefully trained to perform various tasks, such as avoiding obstacles, stopping at curbs, and guiding their handler in a straight line. 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.

WALKING WITH A DOG

Walking with a guide dog involves a partnership between the human and the dog. The VIP holds onto the harness handle, typically with the dog on their left, and communicates with simple commands like “forward,” “left,” or “right,” to which the dog responds adeptly. As the guide dog is not perfect and may occasionally make mistakes, the person must use their judgment and skills to help guide the dog and keep themselves safe.

Although the dog will learn certain routes, the task of navigation must be done by the human. They must therefore be aware of their surroundings for orientation. Some individuals also choose to use a white cane alongside their guide dog for added tactile feedback.

The dog is trained to stop at curbs and stairs, and the person can use this opportunity to listen for traffic or feel for the edge of a step. The dog also avoids obstacles such as low-hanging branches or street signs. When approaching an obstacle, the dog may stop or change direction to avoid it, and the person will feel the movement through the harness.

HOW TO GET A GUIDE DOG?

It is not easy to get a guide dog, and it requires patience and perseverance. The first step typically involves an application to specialised institutions that train and provide these dogs. Once accepted, an extensive matching process ensures the dog’s temperament aligns with the individual’s lifestyle and needs. Training together is the next crucial phase, forming the foundation of their future partnership.

PROS AND CONS OF A DOG

Lopen met een hond is relaxter en zorgelozer, omdat de hond je om obstakels en gevaren heen kan leiden. Hoewel sommige VIPs hun stok nogsteeds gebruiken het lopen met een hond, ben je minder actief bezig met de omgeving verkennen. Dit is ook niet mogelijk, want je loopt sneller. Hierdoor ben je je minder bewust van je omgeving, en orientatie berust mer op proprioceptie. Het vergt dus meer moeite om je te orienteren, en het omgevingsbegrip is minder.

P1: "With the dog, you walk differently. You can't 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."

Participant 2 shared a vivid story about a challenging experience at a train station in Utrecht, illustrating the complexities faced by visually impaired persons (VIPs) in navigation. The participant stepped off the train in Utrecht, where the platforms are notably long, making it crucial to know the correct direction to head in. The participant recounted a moment of confusion about which way they had exited the train, leading to a potential 180-degree error in their world view.

Accompanied by their guide dog Dapper, the participant headed towards the stairs at the end of the platform. Knowing the stairs were some distance away, they instructed Dapper to proceed. At one point, Dapper stopped, leading the participant to believe they had reached the stairs. However, when they instructed Dapper to go downstairs, the dog hesitated. In such situations, it's helpful for the handler to physically check what might be causing the dog's reluctance. In this case, the participant realized they were at the end of the platform, and Dapper was hesitant to move further because there was a drop-off. The participant humorously noted the limitation in communication with a guide dog, as one cannot simply ask the dog for an explanation of their actions.

CONTEMPORARY ASSISTIVE TECHNOLOGIES

OBSTACLE DETECTION SYSTEMS

These systems typically use a range of sensors, including laser, infrared, ultrasonic, and cameras, to detect objects in the user's environment. Information from these sensors is then communicated to the user through various interfaces such as haptic (vibrations), audio, or tactile feedback.

Over the years, a multitude of devices in this category have been developed. Notable examples include the Sonic Guide, Path Sounder, Mowat Sensor, and Sonic Pathfinder. However, as per the research conducted by Chanana et al., many of these devices have now been discontinued, and only a few have continually evolved to stay relevant in the market.

The primary challenge with these systems has been balancing the provision of useful information with the avoidance of sensory overload. Users receive cues about obstacles, but these systems often fail to convey the exact nature or location of the obstacle, leaving a gap in the user's spatial understanding. This limitation, coupled with the inconvenience of carrying an extra device, has led to many of these products failing to secure a strong position in the assistive technology market.

The primary challenge with these systems has been balancing the provision of useful information with the avoidance of sensory overload. Users receive cues about obstacles, but these systems often fail to convey the exact nature or location of the obstacle, leaving a gap in the user's spatial understanding (In 't Veld, 2023). This limitation, coupled with the inconvenience of carrying an extra device, has led to many of these products failing to secure a strong position in the assistive technology market.

OBJECT/SCENE RECOGNITION

Object and scene recognition technologies have emerged as vital tools for enhancing environmental understanding for VIPs. While they may not directly assist with physical mobility, they play a crucial role in interpreting and assigning meaning to the surrounding environment. This technology generally involves the use of cameras and advanced image processing algorithms to identify objects and describe scenes to the user, often through auditory feedback.

These tools are especially significant in helping VIPs recognize and understand spaces and objects that are not easily detectable through traditional assistive tools like canes or guide dogs. They provide an additional layer of information, contributing to a richer perception of the environment.

INDOOR NAVIGATION

Indoor navigation systems are designed to assist VIPs in navigating complex indoor environments like hospitals, universities, and airports. These systems often rely on pre-installed infrastructure, such as beacons, to guide users. However, the implementation of these systems faces challenges due to the high costs and time required for installation. This is exemplified by Visio's ongoing project to install such a system, which has been in progress for over half a year.

The variety of available systems and the lack of standardization also add to the confusion among users. Some systems use apps, while others rely on different technologies, leading to a fragmented user experience. There is a clear need for robust and standardized solutions that minimize dependencies on multiple components that could fail or require frequent updates.

GPS NAVIGATION SYSTEMS

GPS navigation systems have been indispensable in enhancing mobility for VIPs. These systems provide directional guidance along predetermined routes and include landmarks and points of interest for orientation and exploration. Before the advent of smartphones, standalone GPS tools, such as Captain Mobility, were widely used. However, with the integration of GPS functionalities into smartphones, the need for standalone GPS devices has significantly diminished.

One of the main limitations of GPS navigation systems is their lack of precision and detail for small-scale navigation. For example, they might not provide the exact location of a building entrance or detailed movements needed within a confined space. Additionally, GPS systems do not offer real-time environmental information, which is crucial given that surroundings can change rapidly (e.g., a sidewalk may be temporarily blocked).

TACTILE MAPS

Tactile maps are physical representations of spaces that allow VIPs to 'feel' their environment. These maps can be either two-dimensional or three-dimensional and are instrumental in preparing VIPs for navigating unknown environments. Interpreting tactile maps requires specific skills, such as understanding various symbols and textures.

A significant aspect of tactile maps is their customization – they often need to be specifically tailored for individual environments. As one of the core components of this research, the study into tactile maps has been extensive, recognizing the importance of these tools in providing spatial understanding to VIPs.

VIBROTACTILE WEARABLES AND CLOTHING

The development of vibrotactile wearables and clothing is a notable trend in assistive technologies. These devices integrate haptic feedback mechanisms into wearable formats, allowing users to receive information hands-free. However, the success of these products depends heavily on their intuitiveness and the quality of feedback they provide.

Products like the Busclip, which offered limited and wrist-orientation-dependent feedback, highlight the challenges in this domain. In contrast, more successful devices like the Elitac provide more detailed feedback, demonstrating the importance of nuanced and user-friendly design in vibrotactile technologies.

AI & INFORMATION FILTERING

The use of AI in assistive technologies, particularly for information filtering, is becoming increasingly important. AI algorithms can help determine which information is relevant and which is not, addressing the issue of sensory overload. However, a significant challenge is the perception of these technologies as 'black boxes.' Users need to feel in control and assured that they are receiving a comprehensive understanding of their environment. Building trust in AI systems is crucial for their acceptance and effectiveness.

APPENDIX F DTM PROTOTYPE R&D

This appendix describes the process of development of a working prototype and technological exploration. Goal of this exploration is:

- A means for experimentation with a working system: The main goal of the prototype is to open the door to experimentation and exploration with a moving, real-time updating and spatial representation of the immediate environment.
- Inspiration from technology: While building the prototype, understanding is developed of the opportunities of current technology, and what all already exists in the field of especially computer Vision with relevance to my a concept.
- Understanding complexity in the intended system: What are the difficulties of getting the system working and usable and thus what components and technologies need to be further developed or additionally addressed in the design.
- Understanding failure points and influence on interaction and experience: Build understanding and experience of where and how such a system will fail and its impact on interaction. The technology has certain Limitations that affect the final use. This is very difficult to predict when the concept is only theorized.
- Demonstrate the technical feasibility of the concept and explore what research and technological development is needed to achieve vision. If I manage to get such a system working with limited hardware, on my own and with limited knowledge in the field of high-tech product development and prototyping, it is safe to assume that continued development of the technology will lead to a better working system in the foreseeable future.

DYNAMIC TACTILE MAP BACKGROUND

The Dynamic Tactile Map (DTM) is a complex system encompassing various functions that work together to achieve its goals. The key functions include:

- **See/Sense**: This fundamental function involves the system perceiving its environment, the user's movement, and its position in space. This perception is achieved using advanced sensors such as depth cameras or LiDAR, which gather detailed 3D data about the surroundings. This data forms the basis of the system's understanding and interaction with the world.
- **Process/Understand**: This stage involves transforming the raw data collected by the sensors into a meaningful representation of the world. The system processes this data to create a spatial understanding of the environment. It involves algorithms that can identify and categorize various elements within the environment, making it possible for the system to interact intelligently with its surroundings.
- **Intelligent Digital Entity (Owl)**: The Owl acts as the brain of the system, accessing, overlaying, and influencing the output while communicating with the user. It's responsible for decision-making processes, like determining which environmental features to highlight and how to present them to the user. In the prototype, this is left out of consideration, as integrated testing with the DTM and OWI remains topic for future research.
- **Interface**: The interface is the user's window into the digital world created by the DTM. It consists of two main components:
    - **Output**: This part of the interface is crucial as it conveys the system's knowledge of the environment to the user. The interface technology acts as a bridge between the digital realm and the user's perception, determining how effectively the user can understand and navigate their surroundings.
    - **Input**: The input side of the interface facilitates a two-way information flow. It not only outputs data from the system to the user but also allows the user to interact with the system, providing feedback and control.
- **Network**: Networking capabilities enable the system to send and receive data from the cloud. This feature is particularly important for offloading heavy computations to remote servers, thus reducing the hardware requirements and power consumption of the device. Moreover, a networked system allows all connected devices to function as a single entity, learning and adapting from the experiences of all users and environments.

SLAM (SIMULTANEOUS LOCALIZATION AND MAPPING)

A key component in the 'See/Sense' function of the DTM system is the implementation of the SLAM algorithm. SLAM plays a critical role in enabling the system to simultaneously understand its location within an environment and map that environment in real-time.

WHAT IS SLAM?

SLAM is a computational problem and a set of algorithms used in robotics and autonomous systems. The primary challenge SLAM addresses is the chicken-and-egg problem of mapping and navigation: to navigate effectively, a system needs a map, but to create an accurate map, it needs to know its location accurately.

HOW SLAM WORKS

LOCALIZATION

The system uses its sensors (like depth cameras or LiDAR) to identify its position relative to known landmarks or features in the environment. It constantly updates this information to track its movement and orientation.

MAPPING

Simultaneously, the system uses the data from its sensors to build a map of its environment. This involves identifying and plotting objects and features around it, often creating a 3D model or point cloud of the space.

SLAM IN PRACTICE

In the DTM prototype, SLAM allows the device to provide real-time, accurate, and dynamic tactile feedback to the user. As the system moves through an environment, it continually updates its map and understands its position within that map, ensuring the user receives up-to-date information about their surroundings.

The implementation of SLAM in DTM is particularly challenging and essential due to the dynamics of the mobility process. The system must not only map and understand its environment accurately but also do so in a way that can be effectively and quickly translated into tactile maps for the user. This requires a high level of precision and real-time processing, making SLAM an indispensable part of the prototype's functionality.

PROTOTYPE BUILDING

LAYOUT AND DESIGN

The prototype, illustrated in figure F.1 below, features a 60x40 grid DotPad, an advanced electronic Braille display. This display creates real-time 3D maps using a depth camera, differentiating between walkable and non-walkable areas. It provides a top view of the environment, updating as the prototype moves and rotates. Users can 'look around' by rotating the prototype, gaining a spatial understanding of their surroundings.

Portability, while not a primary concern at this stage, has been addressed by attaching the prototype to a walker with a 3D printed frame. This design focuses on user interaction with the map rather than the physical design itself.

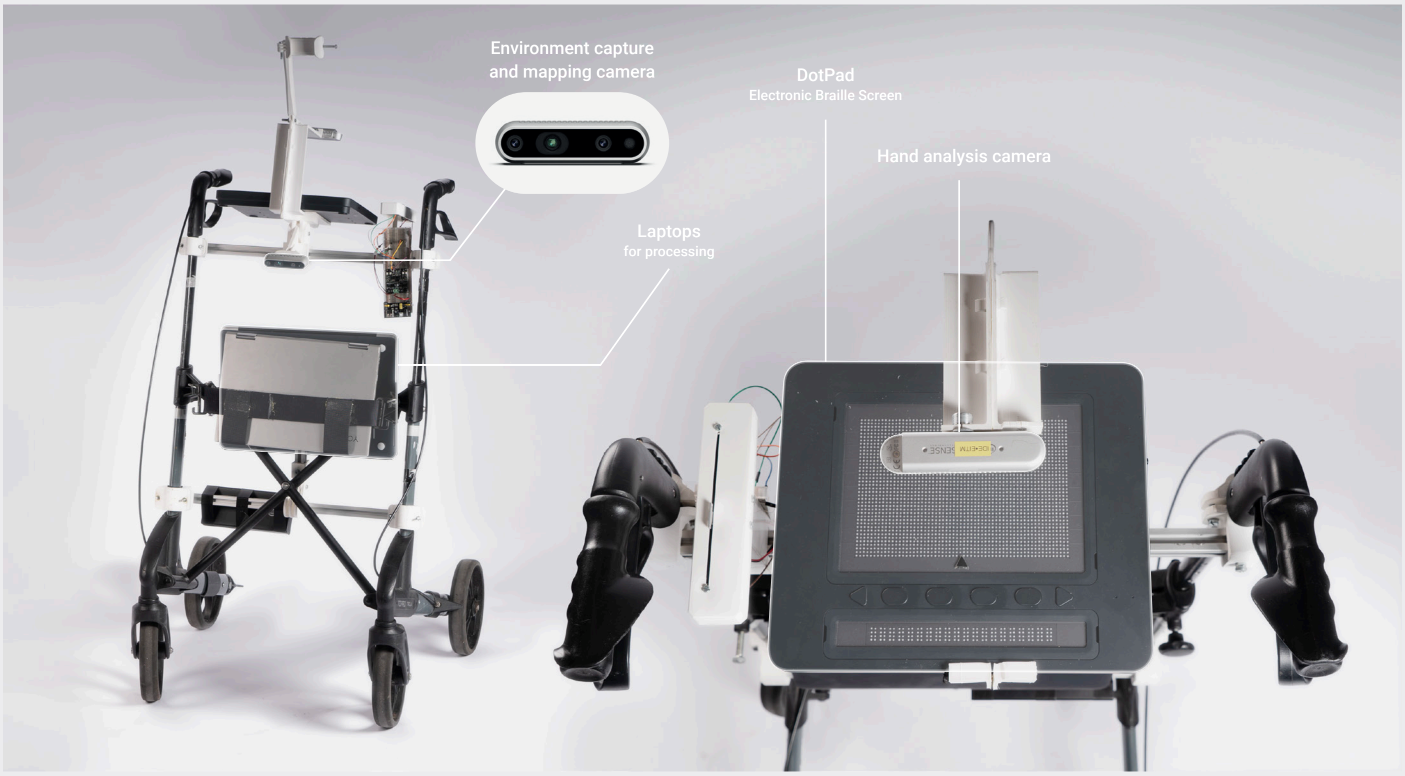

Figure F.1 The prototype

LIMITATIONS

In is important to recognize that the current prototype primarily functions as a research tool for exploring the concept of a Dynamic Tactile Map (DTM). While it is not expected to deliver the full experience of a finished product, for effective experimentation, it needs to operate smoothly and provide an experience as close to the intended DTM as possible. The prototype's most significant limitations are as follows:

1. **Limited Field-of-View of the Camera and unreliable self-orientation**: The current prototype utilizes the camera for self-localization, by matching its current view of the world with a pre-existing map. This method holds promise because, in theory, it allows the device to find its location within environments it hasn't personally encountered but have been mapped by other devices. However, when the camera lacks sufficient environmental detail, the system loses its ability to self-orient. Regaining orientation can be time-consuming and resource-intensive, requiring significant processing power and energy, and it's not always successful. Testing of the device in a simulated environment reveals that this problem occurs regularly and should be addressed in order to achieve acceptable user experience.
2. **Low field-of-view**: The depth camera used in the device has a relatively narrow field-of-view, only capturing a small portion of the space at a time. Because in the prototype the self-localization is solely done through the camera, this narrow FOV often leads to the device losing self-orientation, and reorienting takes considerable time, which is a drawback for experiments. Additionally, this results in a relatively comprehensive process of fully mappingan environment, because the camera needs to be maneuvered around extensively to 'see' the whole space. To address this, a feasible solution is to develop a fused sensor system that incorporates an inertial measurement unit (IMU) to achieve more reliable orientation.
3. **Cameras that can be used in daylight**: Contemporary depth cameras face challenges in daylight conditions due to interference from the sun's infrared light, which affects their ability to perceive 3D environments. Since the concept is expected to be frequently used outdoors, it's crucial to choose camera technology that can function effectively in such environments. A viable alternative is solid-state LiDAR (Light Detection and Ranging). Unlike depth cameras, solid-state LiDAR does not suffer from the same issues in sunlight. However, this technology is currently expensive. Fortunately, advancements in Augmented Reality (AR) and the self-driving car market are expected to make solid-state LiDAR more accessible and affordable.
4. **Screen Limitations**: The screen can only display a binary representation of the environment (i.e., braille dots being up or down) and has a low refresh rate, with the DotPad refreshing approximately every 3 seconds. These limitations impact the quality of environmental perception: The binary display lacks vividness and experiential depth and the slow refresh rate hinders the ability to provide real-time updates. Another important Downside of the screen is that it cannot refresh its

braille dots underneath the fingers and that it has no touchscreen (i.e. knowledge of the different fingers' interaction with the map), which inhibits the user's perception of (relative) movement of the environment or the communication of the device with the user directly through the screen.

Dealing with unknown space: Walking around with the prototype reveals the insight that the device will frequently have to deal with unknown space, and it cannot show or make assumptions about areas it hasn't mapped. An intriguing potential behavior for the device, as an Object with Intent, is to prompt the user to direct it towards unmapped areas. In this role, the concept can be thought of as a 'curious map' eager to map unknown environments, and potentially explore these environments together with the user. For future development of this technology, it is important that the field of view with which the device can see and map the world is significantly increased, as well as the distance at which the device can map the environment.

PROTOTYPING CONCLUSIONS

The insights gained from building the prototype provide valuable information on the requirements for improving the system, focusing mainly on technological enhancements that also impact the experiential qualities of the prototype. These will be further discussed in the chapter on experimentation with the functional prototype.

RELIABLE ORIENTATION/ ODOMETRY

The prototype struggled with maintaining its orientation within the environmental map, particularly near walls, leading to issues in updating the map while moving. This instability is a critical concern for a realistic product. Current odometry relies solely on visual data from a stereo depth-camera. Insufficient environmental reference, as experienced near low-detail walls, results in inadequate data for the algorithm. Solutions include integrating more 3D sensor data for visual odometry, employing a wider field-of-view or multiple cameras, and utilizing a combination of different sensor types and strategies, similar to systems like Apple Vision Pro that use depth cameras, LiDAR, and an IMU for stable and accurate odometry.

LONGER RANGE, HIGHER FOV 3D PERCEPTION

The current 3D sensor's short range (5m) and inaccuracy necessitate improvements. Mapping the environment is time-consuming and error-prone.

Enhanced battery life is essential. The prototype, built on an old laptop with a nearly dead battery, highlights the challenge of power consumption in complex digital devices.

Potential solutions include optimized, specialized hardware with a larger battery capacity. Remote processing can also reduce on-board hardware processing power requirements, although it increases demands on server capabilities and networking hardware.

INTERFACE IMPROVEMENTS

Technological limitations of the DotPad screen are evident. It takes about 3 seconds to refresh the entire screen, hindering real-time movement display. Additionally, the DotPad cannot refresh dots under the user's finger, affecting the accuracy and tactile experience.

These issues prevent the DotPad from effectively conveying real-time environmental changes due to user movement, a crucial aspect for a tactile map in mobility contexts.

IMPROVED INTERFACE FOR RICHER ENVIRONMENT REPRESENTATION

The current system's processing capabilities (2.5-GHz quad-core Intel Core i7-processor, 16 GB RAM) allow for 20 Hz operation for odometry but only 1Hz for map updating. The integration of more sensor data could further reduce this rate.

To address this, more powerful processing capabilities are needed, or cloud processing can be employed to offset the processing load from the portable system.

In summary, while the prototype has provided significant insights, several key areas need addressing for future development. These include enhancing orientation and odometry reliability, extending the range and field of view for 3D perception, improving battery life, and refining the interface for more effective real-time environmental representation. Additionally, addressing the limitations in processing power and speed will be crucial for the system's success.

APPENDIX G DTM EXPERIMENT SETUP

This experiment dives into the practical application and experience of the concept of the Dynamic Tactile Map (DTM).; It aims to bridge the gap between theoretical knowledge and real-world usability and experienceby using a functional prototype that provides the user with real-time spatial environmental perception. Initial attempts with pin art systems and 3D-printed maps were insufficient, failing to provide an accurate, moving representation of the environment. This hinders the ability to gather useful insights about the concept.

In the context of this experiment, the DTM's ability to provide a tactile representation of the surrounding environment was assessed. Participants, all of whom are VIPs, interacted with the DTM in a controlled setting. Their responses, interactions, and feedback form the core of the data presented in the following appendix.

MVP

The prototype is only the MVP of the conceptual DTM due to its ability to provide dynamic spatial distance perception. Although it is far from a realistic product, and doesn't yet offer the full experience intended, it provides valuable insights that can be used for the design of a more advanced DTM. In the experiment, the focus lies on the potential and points of improvement for the map to:

- enhance wayfinding: It should offer a detailed overview for understanding the environment, aiding in route planning, self-orientation, and movement based on environmental cues.
- allow easily perception: The map should be intuitive, requiring minimal conscious effort to interpret, and should work together with other senses to create a coherent perception of the environment.
- vividly and detailedly communicate the environment: A rich environmental perception encourages engagement, curiosity, and exploration.

METHODOLOGY

PROCEDURE

The participant is picked up from the station and brought to the designated studio. Here, all the necessary equipment, including the prototype, cameras and other necessary equipment are set up and the participant is welcomed and made comfortable.

EXPLANATION AND CONSENT PHASE

This involves offering refreshments to the participant and engaging in a brief informal conversation to establish rapport. The researcher explains the experiment in detail, outlining what the participant can expect and addressing any questions or concerns. During this time, the researcher also discusses the potential risks involved in the experiment and the safety measures put in place. It is crucial at this stage to obtain informed consent from the participant, ensuring they understand their role and rights within the study.

Then, a preliminary interview is conducted. This interview aims to capture the participant's mobility and navigation style, understanding their personal strategies and experiences in navigating different environments, which serves as a valuable reference point for later analysis of how the participant interacts with the moving tactile map.

EXPERIMENTATION PHASE

The experimentat begins with an initial exploration where the participant is asked to navigate to a designated endpoint, described as the door of a café, using their white cane. This enables them to get an initial understanding of the room, which allows them to lateron describe to the researcher what they recognize in the DTM prototype.

Then, the participant is introduced to the prototype. First, they are asked to use this map to describe the room, and how this matches with their mental image of the space from the initial exploration. Then, they are asked to navigate through the space in various scenarios, ranging from simple to more complex routes. During this process, participants are be encouraged to continuously articulate their thoughts, describe their thinking processes, strategies, and perceptions of the environment and the researcher asks them questions on these topics.

FINAL INTERVIEW

Finally, the participant and the research team engage in a detailed discussion about the moving tactile map and the participants experience of it. The participant is encouraged to share their thoughts on how the device could be improved or modified to better suit their needs and preferences. The feedback gathered during this session and during the experiment is crucial for the next stage of the project, where it is used for the design of an enhanced DTM.

SAFETY MEASURES

The research design includes accessible informed consent procedures, reassurance of withdrawal rights, and the opportunity for questions. Adjustments are made to minimize risk, such as ensuring no sharp edges or falling hazards are present, and the researcher remaining close to guide and assist.

PILOT TEST

A pilot test is conducted with a fellow student who is not informed about the specific focus on visually impaired individuals. This trial helps refine the experimental process and ensure smooth execution and comprehensibility.

PERMISSIONS AND APPROVALS

The research is conducted under the supervision of the Human Research Ethics department of the TU Delft, and participant recruitment aligns with established connections from previous studies and interviews.

EXPERIMENT SETUP

The experiment was conducted in two simulated environments within the Faculty of Industrial Design Engineering, simulated to mimic real-world conditions with variable obstacles. These environments were specially designed to be easily interpretable by the DTM prototype and to provide clear and navigable maps for the participants.

In the experiment room, large monitors showed a live stream from cameras recording the participants' hands interacting with the displayalongside a black and white view of the map itself. This setup enables the researcher to continuously watch and understand the participants' interactions with the map as they navigate the environment. The prototype and cameras were wirelessly linked to a central control center, allowing a single researcher to control and monitor the prototype remotely and conduct the experiment efficiently.

In the experiment, large monitors displayed a live stream from cameras that captured the participants' hands interacting with the display/map and the map itself (i.e. what the participants were 'seeing'). This setup allowed the researcher to continuously observe and understand the participants' interactions with the map as they navigated the environment. The prototype and cameras were wirelessly connected to a central control center, which enabled the experiment to be conducted by a single researcher.

A control center is built that wirelessly connects to the prototype and allows for the remote monitoring and control of the prototype:

The zoom of the prototype can be controlled by an external slider, in addition to the slider on the rig. Moving the slider of the control center also controls the slider of the rig so the participant is not confused by the zooming.

A livestream of the map view (i.e. the 60x40 black/white grid) and feed from the camera that films the hands is transmitted for the display on a large screen, that allows the researcher to observe the interaction of the hands during the experiment.

PARTICIPANTS

Eight visually impaired individuals participated in this experiment. All except one were fully blind. Participants were selected to range from technologically apt to relatively inexperienced, in order to get a broad spectrum of interactions with and insights in the prototype.

EXPERIMENT SETUP

The experiment was conducted in two simulated environments within the Faculty of Industrial Design Engineering, simulated to mimic real-world conditions with variable obstacles. These environments were specially designed to be easily interpretable by the DTM prototype and to provide clear and navigable maps for the participants.

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DATA COLLECTION AND ANALYSIS

Video recordings from multiple angles document the informed consent process and interviews,

Explicit effort is put into the prototype and room setup for comprehensive data capture and monitoring of the participants' interaction with the map in relation to the environment, activity and thought-process because they are essential to understanding the user's experience and the workings of the prototype, to further develop the technology. Therefore, 3 cameras document this interaction: two that are mounted on the prototype, one that records the tactile map interaction from a top-view of the participant's hands, one that records the participants from the front, and a stabilized camera held by the researcher to capture the wider context. These video feeds are lateron synchronized for easy data analysis. Research and interview data are analysed in a qualitative fashion by thematic coding.

APPENDIX H DTM EXPERIMENT RESULTS

This appendix presents the detailed findings of the A8B Dynamic Tactile Map (DTM) experiment. The purpose of this experiment was to evaluate the efficacy of the DTM in enhancing spatial awareness and navigation skills in visually impaired persons (VIPs). Quotes from participant's are kept in Dutch, to maintain their originality.

1 SPATIAL LAYOUT & ROUTE PLANNING

1.1 ENVIRONMENTAL PERCEPTION AND SELF-ORIENTATION

1.1.1 PARTICIPANTS' UNDERSTANDING OF SPATIAL LAYOUT

The experiment revealed participants' capability to comprehend spatial layouts and relationships, and to plan their routes accordingly. They demonstrated an ability to identify landmarks such as pillars or paths using the tactile map.

P3 explains how his spatial environment perception of through the DTM allows him to perceive his larger environment:

"Je kan voelen waar obstakels zijn en hoe je er dus omheen kan lopen. En dat het je een groter beeld geeft van de omgeving dan wat je hebt als je alleen maar met een stok loopt. Als in dat je beeld van je omgeving als je met een stok loopt is maximaal anderhalve meter. En met dit prototype is je beeld een paar meter om je heen. En je beeld is niet alleen voor je, maar ook links en rechts."

P3 explains how the device enables and stimulates him to think spatially, and think ahead:

"Het daadwerkelijk zien, en ook zien dat het je dwingt om ruimtelijker te denken, ruimtelijker te navigeren, dat vond ik heel mooi om te zien. (...) Je wordt gepusht om met de stok alleen maar te denken over de meter voor je, dat is letterlijk het enige wat je hebt. Hier heb je ineens heel veel meer data. Je wordt ook gepusht om die data te gebruiken."

The very first time he is exposed to the map, P1 explains how he perceives the environment. IHe immediately links elements on the map to environmental elements that he encountered earlier, through the spatial layout:

"Dat ding wat rechts van mij zit, ik weet niet wat voor ding het is, maar dat obstakel dat rechts van je zit als je naar de muur loopt, zeg maar. (...) En dat die ook dan in de bocht ook er is, zie ik dan. [Dat herken ik] omdat dat, zeg maar, de hoek omgaat."

P1 demonstrates his awareness of the path:

"Je hebt natuurlijk het pad gewoon, die loopt gewoon door. En dan zie ik inderdaad op een gegeven moment aan het einde van het pad zie ik, zeg maar, een blokje, dus de pilaar, zeg maar. En daar kan je dan, ja, daar kan je dus op twee momenten omheen, zeg maar, en dan kun je doorlopen tot het eind."

P2 gives a clear example, based on his experience with the prototype, of the benefit the product brings through its spatial overview, compared to a dog, which 'abstracts' the spatial overview away from him:

"Ik heb een park waar de hond niet goed [slaagt om me de weg te helpen vinden.] De hond weet natuurlijk prima de weg, maar ík weet niet precies waar ik ben. De paadjes lopen nogal kris-kras, en mijn hond, als ik zeg links, dan wil hij ook wel eens het eerste pad links overslaan. Dus ik ben daar vrij snel op een punt wat ik niet ken. Dan ik moet gaan reconstrueren: Waar zit

ik nu? (...) ik moet nu bewegen om te checken of mijn idee van waar ik zit goed is. Ja. Ik zeg naar links en dan denk ik dat hij het eerste pad links neemt. En het duurt even voordat ik merk dat hij het tweede pad genomen heeft. (...) [echter met het apparaat,] als ik stilsta en ik krijg een plaatje, dan is er veel meer kans dat ik herken waar ik ben (...) alleen dat al zou ik op de hoek de kaart gehaald hebben, dan had ik gezien dat er links nog een pad was."

P3 shows his detailed overview of his surroundings that he uses to move through it. it is also seen that he links element on the screen to real world obstacles he encountered earlier, and this that he makes a mental link between the map and his real world environment:

"voor mij is de ruimte helemaal leeg. Rechts voor mij is een stukje van de muur, denk ik. Ik neem aan dat als ik zo meteen recht vooruit loop en dan weer een stuk naar rechts ga, ik uitkom bij de muur waar ik heen wil. Ik zie rechts van mij nog steeds het obstakel waar ik net omheen ben gelopen."

At a certain moment P1 gets stuck due to a sensor error that made the quickest route to his destination seem blocked. He decides to find an alternative route through the room. He shows that he has great overview of the spatial layout and he is able to immediately point out and show an alternative route on the map:

"Dan ga ik de andere route proberen, want ik zag twee routes."

When asked to point out the route on the map, he explains with his finger:

"Ja, dan moet ik zo meteen eerst naar mijn beginpunt (...) dat zit ongeveer hier denk ik. (...) [dat baseer ik] pp het in mijn hoofd hebben. Ik ging hier de bocht mee en dan zou ik ongeveer hieruit komen. En dan moet ik eigenlijk via die kant zo daarheen."

When asked how he uses the map to understand the space, he explains:

"Ja, je kan meer visueel gezien een kaart in je hoofd vormen, hoe iets eruit ziet, omdat je het letterlijk in de praktijk ervaart, zeg maar."

He is asked if this map translates to a mental image of the space, he replies:

"Ja, doordat het tastbaar wordt voor mij wel."

P1 shows his capability to understand and trace back the route that he walked through the room: "Ja, want ik ging... Kijk, nu is het al... Kijk, dat ging zo. Dan liep ik hier zo vast. (...) hier zat eerst echt een hele lijn, zeg maar. En dit pad zo hier naartoe, naar dit punt was er net niet, zeg maar. Echt heel duidelijk voor mijn gevoel. (...) Ik herkende dat straks niet, zeg maar. (...) Soms kunnen details juist goed helpen en andere keer niet, soms heeft een overview juist ook het nadelige effect natuurlijk. (...) dat hij dan net niet die specifieke kleine stukjes goed pakt."

P4 describes an egocentric view that also shows the space behind you, so you can see how far you are through a space: "Hoe nodig dat eigenlijk is, is dat je dus beter weet waar je in de ruimte zit en hoe dingen ten opzichte van elkaar liggen. Kijk, ik weet bijvoorbeeld op deze manier nog niet goed hoe ver ik nou ben tussen de achterwand en de voorwand.Ik moet bijvoorbeeld een beetje gokken, ik ben net langs die zijwand. Ben ik nou in het midden?"

P7 shows his spatial overview and spatial capabilities through an understanding that there is an obstacle to his right, which he successfully circumvents:

"Ik denk dat ik hier zo met een bochtje naar rechts ga. Er staat hier wel een obstakel dichtbij, dus ik denk dat als ik een beetje zo ga, dan een beetje naar rechts. Oké, dan ben ik er voorbij"

He scans the new space that he enters,

concludes that there are no paths leading towards his destination from this space and decides to turn around (It should be noted that there was a path that led him out of this space, however due to a sensor error, the DTM displayed this path as a wall.

"Ik denk dat ik vast kom te zitten hier. Voor mij hebben ik allemaal puntjes komen te staan op één centimeter vanaf mijn puntje. En hier ook een beetje rechts staat het allemaal dichtbij. En als ik hier dan voel, is dat ook allemaal een muurtje. Ja. En het is hier wel nog een klein beetje leeg voor mij, maar ik denk misschien niet zoveel. En nu, ik voel hier wel dit, maar het maakt geen beeld uit van… Ik ga keren."

This example beautifully shows that he is able to scan and overview a space without needing to extensively explore and map the space by moving through it, as would have been necessary with the white cane.

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.

The first time that P7 is exposed to the prototype, he is asked to explain what he perceives about his environment. It can be clearly seen how P7 scans the space and follows the walls with his fingers. He tries to recognize elements from the environment he earlier encountered. He notes that the corner is not a straight angle.

"Ik voel nu aan dit pijltje, dat gaat rechtdoor. Dus ik voel hier de straat. Wat ik wel vond is dat linksachter loopt dat niet helemaal in een rechte hoek, dat loopt een beetje schuin daar. Dus dat voel ik. En ik weet wel hoe de route ongeveer loopt maar die pilaar, die merk ik hier nog niet zo gelijk direct. Maar ik zie hier wel dat hij in zo'n soort… Dus ik voel hier het verschil niet tussen hoe hoog de omheling is om het zo te zeggen. Wel de route, maar of dat dan een pilaar is of een muntje."

P4 explains that he was able to understand the space through its walls and passages:

"Het kan dus goed werken, het lukt best vaak om die doorgang te vinden. (...) Ik kon natuurlijk wel bepalen waar de wanden zaten."

P1 explains how he forms a comprehensive mental overview of the space and routes through it:

"[ik gebruikte de kaart] in eerste instantie natuurlijk om een beeld te krijgen van de omgeving, van hoe kan ik ergens heen, vanuit de ene kant van de ruimte naar de andere kant. (...) en dan ga je ook al kijken van, zie ik toevallig bijvoorbeeld kleine steegjes die ik kan gebruiken als herkenningspunt, want als ik dit steegje heb gehad, dan kan ik die en die kant op."

It can be seen here that he uses the DTM to form a mental image of the space, which he can later use during movement through it, for example using little alleys that he earlier perceived for his orientation.

P1 plans his path throughout the whole room and locates his destination. He finds this by combining the map with where he hears the music that is played at his destination:

"ik zie een hoek van de ruimte, zie ik hier. En hier nog helemaal zo, dan zie je een heel klein doorgangetje. En dan komt er weer een stuk muur dan tegenover mij. En dat loopt dan een uitstopping naar boven en een uitstopping naar rechts. (...) Dan zou ik gokken dat hier de kroeg ongeveer moet zitten." When asked how he found his destination on the map, he replied: "op basis van de muziek, zeg maar."

P4 explains how, in contrast to other assistive technologies, the prototype allows you to traverse open spaces and orient yourself spatially:

"Er is niets zo moeilijk als je helemaal niks ziet als 'ga maar rechtdoor'. (...) Er is niks moeilijker dan je op een voetbalveld te oriënteren als je de randen niet ziet. Want je hebt geen idee (...) waar je dan bent. Met zo'n systeem kun je dat wel doen. (...) dan kan ik zo voelen of ik op de middenstip sta of niet. En als je die visuele referentie niet hebt is dat vreselijk moeilijk tot onmogelijk. Een voetbalveld is natuurlijk een ereem voorbeeld. (...) [het gaat echt om] verhoudingen, waar je bent in een ruimte, waar je je bevindt ten opzichte van andere dingen, ten opzichte van een deur."

P7 's process of mental mapping of the enviornment and orientation based on the map can be beautifully seen. It is also interesting to see how he tries to understand what obstacles are in his environment:

"hier wordt het wel smal, en dat had ik niet door met mijn tasstok toen ik hier liep, dus hier heb ik wel het gevoel, hier heb ik wel meer informatie dan met je tasstok, omdat ik nu denk van: hey, dit is even een smalle doorgang. En wat voel je nog meer allemaal, ook behalve, dus je voelt het pad. (…) En dan heb je hier een opening, maar hier verder heb je ook nog een opening. Dus je hebt er twee, maar ik weet nu niet wat mijn doel is. Dus, dus, dus, kijk, en hier is een blok. (...) Maar ik weet nu niet of ik nu dat eerste paadje naar rechts moet. (...) Dus ik denk dat ik nu 1 of 2 meter vooruit moet, en dan kan ik naar rechts moet. (...) Dus als het goed is kan ik hier gelijk naar rechts, en dan kan ik een beetje verder ook naar rechts, maar ik voel dat hier, hier staat ook nog iets hoor, het zijn nu 3 uithangen dan nu. Ik kan hier naar rechts, en dan kan ik een beetje vooruit ook naar rechts, en dan kan ik daarachter ook nog naar rechts, maar dat is iets kleins, want het is hier, hier is iets breder, en daar is iets wat een beetje korter is, als het goed is. En dat is ook een paal iets, oei wat is dit, ik weet niet wat het is, maar het is ook iets korts. Het is wel al lang een ding, rechts van mij, het is iets langs, iets langs waar ik niet overheen kan."

It is seen how P7 quickly scans and overviews his environment. He explains that it is great that you can feel the space behind the nearest obstacles and walls, so you can perceive the spatial layout:

"Ik voel hier voor mij dat er iets staat. Wat ook wel goed is, dat je daarachter [de omgeving kunt voelen]… Dus ik voel hier iets in de vorm van een, een soort omgekeerde T of zoiets, met iets wat links daar nog aanhangt. En daarachter kan ik ook voelen. Er zit ook nog iets achter. Dat is ook wel mooi, dat je kan voelen in die kaart: Oke, dan kan ik daar omheen. Oh, daar kan ik niet omheen. (...) Oké, maar ja, ik weet wel dat ik er wel eens omheen kan, dus kan ik dat even doen?"

P3 shows how he focuses on a part of the room during his overview of the environment ahead of him:

"Voor mij is de ruimte helemaal leeg. Rechts voor mij is een stukje van de muur, denk ik. Ik neem aan dat als ik zo meteen recht vooruit loop en dan weer een stuk naar rechts ga, ik uitkom bij de muur waar ik heen wil. Ik zie rechts van mij nog steeds het obstakel waar ik net omheen ben gelopen." When asked why he does not feel the space left of him, he replies: "omdat ik net in mijn hoofd bedacht heb, ik ga naar voren, rechtsaf en dan nog een keer ergens rechts. Dat is wat ik net in mijn hoofd, toen jij aanwezig waren deur zat. En dat is dus mijn focus. Alles wat links is, ik weet dat ik nu niet naar links wil. Misschien had ik wel naar links gemoeten, maar dat was niet wat

ik in mijn hoofd had. Dus dat negeerde ik dan voorlopig maar even bij het voelen."

CONCLUSION

Participants showed a strong ability to understand spatial layouts and relationships using the Dynamic Tactile Map. This understanding enabled them to navigate through the environment effectively and identify important landmarks.

1.1.2 A NATURAL TENDENCY TO EXPLORE

The spatial perception of the environment enabled the participants to look beyond their direct path. When walking a route, participants were often interested in 'exploring' space from afar, also if this space was not relevant for their current route. Participants tried to understand what this space looked like, and what was in that space. The interface, despite its binary, bland nature, instills curiosity in the participants, because they are able to perceive new space, which they were originally not aware of.

P1 explains how he would try to perceive details about the space, the 'middle of the room', which was not part of his route (and would only later be made accessible to him):

"Wat mij bijgebleven is dat je aardig goed op basis van de kaart wel kan zien waar je ongeveer zit, zeg maar. Als je gewoon even de tijd neemt om het goed even te laten refreshen, zeg maar. Dan krijg je wel een aardig goed beeld ook, wat ik zei over het stukje wat in het midden zit en zo."- Wat bedoel je met het stukje dat in het midden zit? - "Nou, het stuk waar je eigenlijk niet langskomt, dat daar ook details van te zien valt."

P1 explains what role the DTM could play in his daily life, he explains that the increased spatial overview would let him elore unknown areas and travel to new places more often:

"dit helpt sowieso om op wat onbekendere omgevingen gewoon te gaan exploreren, zeg maar, dat je ook wat makkelijker zegt, oh, ik ga er eens, ik ga gewoon eens even ergens heen, zeg maar, wat makkelijker, zeg maar, zonder dat je niet meteen een hele route in je hoofd al weet, dat je honderd keer moet hebben gelopen en zo. (...) [met de stok] dat doe ik wel minder, omdat ik niet een compleet beeld heb van om me heen, zeg maar."

P1 shows a natural tendency to elore the space around him, even though this is not important for his current route: When walking through the first route, he starts eloring and mapping the space that is to the right of the table that delimits his path by himself:

"Dit, zeg maar, wat het is, het midden. Maar dat kan niet echt uitkomen wat dat is, zeg maar."

When asked why he chooses to explore this location on the map, even though it is not relevant for his current route, he replies:

"dat is wel interessant om te weten, want als je bijvoorbeeld wel aan het zoeken bent en stel je voor, je weet het even niet, en je vraagt even aan iemand van joh, waar loop ik nu, zeg maar. Dan kunnen ze zeggen van, ja, je loopt nu om dit en dit heen. Dus dan wil je graag wel weten waar je omheen loopt, zeg maar. (...) stel je voor dat dit bijvoorbeeld een terras is, dan is dat wel handig om te weten dat je om een terras heen loopt, inderdaad. Dus die herkenning van wat jij daar, als jij nu zou weten wat dat is daar. (...) [dat is dus goed] voor je eigen oriëntatie, zeg maar. En ook voor, stel je voor dat je even je weg kwijt bent en je wilt even aan iemand kenbaar maken, zeg maar, waar je eigenlijk moet zijn op je route, dan kan je dat als herkenningspunt gebruiken om uit te

leggen, goh, ik moet daar eigenlijk omheen."

While parked at the start of the course, with an alternative route to his right, P3 first explains how he would traverse the path he has previously walked. Then, spontaneously, he observes that he could potentially take a direct right turn, circumventing the original path. He describes this alternate route, which he is permitted to elore later in the experiment. The overview provided by this vantage point prompts him to consider alternative routes, sparking his interest:

"Ik heb nu gezien dat ik recht naar voren moet lopen om dit obstakel rechts van mij heen te gaan. (...) dat kan ik hier net niet helemaal lekker zien; misschien dat je ook nu meteen naar rechts zou kunnen. En dan via de rechterkant hier om dit obstakel rechts heen."

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 indicates that this perception of the environment, even though the interface is bland, inspired curiosity.

1.1.3 SPATIAL OVERVIEW FOR ORIENTATION

The spatial overview helps the participants in their spatial orientation, and allows them to understand where they are within a space, how they are turned, and where their destination is.

P2 recognizes his location due to the recognition of a cabinet, which he uses throughout the experiment as a landmark:

"ik moet nu rechts het beeld van het kastje zien te krijgen. (...) Ik sta tamelijk aan de rechterkant van het pad, en ik zie nog steeds iets wat ik denk dat is het kastje."

P2 shows that he is able to use a recognizable environmental element for his orientation:

"Ja, ik was in de buurt van de vrije ruimte. (...) Nou, ik zou hier nog steeds het kastje lokaliseren." .

P2 explains the importance of landmarks:

"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.

1.2 LOW DETAIL, BINARY REPRESENTATION LIMITS RECOGNITION AND WAYFINDING, BUT IT'S A START.

1.2.1 BINARY DISPLAY

However, the current low-detail binary display of the DTM limits the richness of environmental perception, which is crucial for understanding the environment, self-orientation and recognizing your goal

P3 explains his need for more detail in the map:

"En ik kan me voorstellen dat hoe meer detail je in de kaart hebt, hoe meer context je in de kaart kan voegen, hoe minder hulp je nodig hebt. (...) het soort obstakels, de afstand, dat soort dingen."

P3 explains that his perception through the map is not detailed enough to recognize elements of the environment which he would in this case need to see where his goal is:

"En dan gok ik, dat vind ik dan lastig, het zou kunnen dat hier ergens, bij een van deze oneffenheden, de deur zit, maar daarvoor is de detail te weinig om dat te zeggen. Maar goed, vanuit mijn herinnering dacht ik, dat ergens een stukje deze kant op de deur zou zitten. (...) de huidige implementatie, zeg maar, die biedt je wel het overall 'oké, hier kan ik lopen, dus dit zou een haalbare route zijn', maar biedt je niet het detail om de soorten obstakels van elkaar te onderscheiden (...) je kan wel detecteren dat er een obstakel is, maar je kan niet detecteren wat dat obstakel precies is."

He explains how the recognition of his enviornment can help him in his wayfinding:

"Sommige obstakels hebben bijvoorbeeld een muur, je weet dat als je een deur zoekt, dat de deur in een muur zit. Je weet dat je dan dus een muur op een andere manier moet interpreteren dan bijvoorbeeld een tafel. Een tafel is iets waar je omheen moet, de muur is iets waar je misschien juist wel naartoe moet, omdat daar de deur in zit. En zo kun je door te weten wat het obstakel is, kun je daar je conclusie aan verbinden."

P2 explains the importance of recognizing landmarks and that a binary preview would not be enough for him to spatially orient himself:

"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. Dat kolom, zal ik maar zeggen. En dan hoor ik opeens iets hards. Dat is interessant, dat is iets. Dat heb ik even gevoeld. O, dat is een kastje. Ik weet niet hoe ik dat ervaren zou hebben als ik [de verkenning met de stok] niet gedaan had van tevoren. Dus als ik straks zo'n baken tegenkom en ik zie alleen maar de puntjes een beetje uitstulpen. Ja, dan zal dat wel iets zijn, maar wat is het? Een gat in de muur?"

P2 tries to find his orientation but, because he cannot recognize the environmental elements, he is uncertain if he is indeed where he thinks he is:

"Nou, ik voel, A, vrij pad voor me. Hier komen we waarschijnlijk op die grote ruimte die er gewoon is, hè? En hier is nog een stukje muur. Ik ben er niet zeker van of dit nog een stukje kastje is, het zou kunnen, hier. (...) , die eerste. Ik dacht dat ik er al voorbij was. Maar misschien is dat niet helemaal zo."

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."

P7 is zoomed out on the map. He notes that he can now see the larger room layout:

"Ja, dan zie je wel dat het die schuine hoeken daar linksvoor, die is wel een beetje kleiner nu. Maar dit voel je wel… Oh, hier is dat blokje, oké. En is dit hier de pilaar? Oké." However, this low detail does not allow him to recognize his goal: Want kijk, wat ik nu wel ook niet weet… Die kroeg, waar zit die dan hier precies, het doel? Ik heb nu wel hier een dingetje… Waar is mijn einddoel? Dat zie ik niet op de kaart. Weet je? Dus ik zie nu wel dat de straat zo loopt en dan naar rechts. Wat dat dan precies gaat uitzien, weet ik nu niet."

P4 describes that he would 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:

"Het apparaat geeft inderdaad een overzicht van de ruimte. En ja, in concept helpt dat zeker om te navigeren. In de praktijk is het ingewikkeld, omdat hij natuurlijk nog niet in alle details altijd even snel realtime volgt. En omdat het dus nog heel erg weinig, je weet wel dat het iets is, maar je weet niet wat het is. Maar als dit realtime zou volgen, dan kan ik hiermee zeker wel later veilig door de ruimte loodsen en ook op een bestemming komen."

When asked to relocate a door that he earlier pinpointed in the environment, P3 explains how it is difficult to recognize elements in the map which renders it impossible for him to relocate this element without an elicit process of trying to find it on the map:

"Dit vind ik dus lastig (...) Vanuit mijn conclusies eerst had ik gezegd: ik moet er naar voren en een stukje naar rechts, en dan zou de deur dus zeg maar links voor mij moeten zijn, maar ik heb geen manier om dat te checken. Dus je weet wel waar je ongeveer naartoe zou willen gaan, alleen je kan nu dus niet met de kaart checken of dat daadwerkelijk de deur is die daar is. Kijk, dit blok, deze twee, ik neem aan dat dit de muur is (...) Maar ik kan dat niet checken."

P3 explains that recognizing elements in the environment is important to find your destination, and that without it, you can only guess where you would go based on the map:

"[je weet niet waar je naartoe moet navigeren] doordat je, waar we het net over hadden, niet je duidelijke einddoel op de kaart kan voelen. (...) Maar als je eenmaal een soort cue hebt van waar wil je heen, dan is het veel makkelijker."

P3 mentions that he is unable to identify the specific door he is searching for on the map. Consequently, he has to deduce its location based on his previous movements and initial understanding of where the door might be:

"Ik heb geen enkel referentiepunt van waar de deur is. Ergens in mijn hoofd had ik gezien, zeg maar, je moet een stuk naar voren, naar rechts, en dan nog een klein stukje naar rechts. Maar dat is ergens wat ik in mijn hoofd heb opgeslagen. Ik heb na dat ene moment geen enkele referentie meer waar de deur was."

Participants need a better recognition to be able to track and use landmarks for their orientation and movement:

P3 explains his desire to recognise and

constantly track his destination, to use this as a reference point for his movement. When asked what the effect is on his orientation of the constant turns and the many questions that he receives during the experiment, he replies:

"Dat ik geen oriëntatie meer heb. En het feit dat je visueel hebt je continu een reference point waar je naartoe wil. Ik heb dat niet. Eén keer heb ik een soort hint gekregen waar ongeveer de deur zou moeten zijn. Dan heb ik dus opgeslagen, oké, ik moet rechtsaf, rechtsaf, en dan zeg maar, je moet twee bochten maken, en dan ben je er ergens een keer. Maar dat is het enige reference point wat ik heb."

When asked how this problem could be solved, he replies:

"Door, de eerste stap is aan te geven waar de deur is."

P3 explains his need to constant awareness of reference points in the environment and their relative location (in this case, his goal):

"je hebt een punt waar je heen moet en dat heeft dan automatisch ook een richting vanuit je huidige oriëntatie. Stel je zet dat punt op helemaal rechtsboven, dan weet je dat ik naar rechts en naar voren moet. Terwijl nu heb ik geen idee wat mijn einddoel is. En doordat je dus, waar we het net over hadden, continu eigenlijk rond loopt, moet praten en ook geen stok hebt, ben ik inmiddels mijn oriëntatie kwijt. (...) Je hebt geen enkel reference point. Als die deur bijvoorbeeld geluid zou maken, of jij zou bij die deur gaan staan. Stel jij zou bij die deur gaan staan, of je legt een telefoon met muziek bij die deur, dan zou ik weer direct in één streep naartoe lopen, omdat je dan een bepaalde oriëntatie hebt. Maar dat heb ik nu niet. (...) Maar je moet je wel bedenken, in het echt heb je [era informatie uit de omgeving die je helpt bij het orienteren] natuurlijk ook, hè. In het echt heb je ook niet nul info"

P1 explains that he wants to be able to recognize environmental elements to use them as landmarks, that help him understand his current heading, and the direction towards his goal:

"Het is wel spannend hoor, zo tegen de kaart. Ik had in het begin natuurlijk makkelijk oriëntatie aan het kastje. Maar nu is het kastje bijna verdwenen. (...) [Als ik dat kastje kan blijven gebruiken als orientatiepunt] dan weet je minstens nog een beetje waar ik ben. Ik zei al, hè? Noord."

P2 mistakes a trash can as his goal based on its top-view. However, his goal is actually in the other corner of the room. This shows that his inability to recognize environmental elements leads him to make mistakes in his wayfinding:

"Ja, ik zie dat hier veel ruimte is. Dus daar wil ik eigenlijk heen. Hier ergens was die kroeg. Ja, dan… Ik denk dat die hier is. Maar ik weet het niet zeker."

P1 notes that he would want to be able to recognize landmarks that he earlier encountered in the map, for his orientation:

"Dat je bijvoorbeeld bij wijze van spreken iets als een markering ofzo kan zetten. Dat je een point kan vastzetten van oké, ik moet hier heen. Zodat je bijvoorbeeld dat je dat gewoon herkent als je via een andere weg er heen gaat, dat je het nog herkent. Of dat als je inzoomt dat je het ook nog vindt"

He also notes that he would like to be able to perceive the heading of this landmark when he's further zoomed in, so that he can maintain his heading.

P1 gets stuck, because he wrongfully recognizes a certain location as his destination. He gets stuck. When asked how that happened:

"Nou, omdat ik niet precies weet welk stukje echt het café was. (...) [Daarvoor heb ik zou ik behoefte hebben aan] een soort van logootje of zo."

P7 describes that when he walks outside, he would like to be able to perceive where road-crossings are:

"Waar is je een zebra, en dat die zegt van, op één uur is een zebra, en dan weet je, en dat dan een beetje rechts, honderd meter verder, om het zo te zeggen"

When asked why he would want to recognize the environment better in the map, he explains that for is formation of a cognitive map of the environment, he keeps in mind that certain elements are non-permanent, and that he would not use these as landmarks:

"Sommige obstakeldingen zijn tijdelijk en sommige vast. En als je weet bijvoorbeeld weet van: het is een muur, dan weet je dat je daar altijd op kan bouwen. Maar als dat een auto is, die staat er niet altijd. (...) op het moment dat je weet dat daar iets tijdelijks staat, dan ga je bedenken: oh, die zou er niet kunnen staan de volgende keer. Dan ga je dat niet als herkenningspunt gebruiken"

P4 explains that finding elements in an environment is difficult for VIPs, and that the ability to recognize and find such elements through the map would greatly benefit their mobility:

"Het wordt pas moeilijk op het moment dat je een punt moet vinden. Een deur, een afslag, zeker als het meerdere afslagen zijn. Als je op een precies punt moet uitkomen. Een lift, een trap. Daar wordt het moeilijk. En daar moet je mensen extra gaan begeleiden. En het leuke hiervan kan zijn als je dat soort dingen zou kunnen aangeven. (...) Dat is wat hier nog heel erg aan het werken is."

Participants were not able to understand the space that they did not cross, because they lacked meaningful perception. Therefore, they were not triggered by environmental stimuli that incited their curiosity, leading to the conclusion that lack of meaningful perception limits the curiocity and tendency to explore.

P1 describes availability of new space, which would not have been available when walking with the stick. It is observed that he actively wonders what it is that he perceives in this space:

"Je hebt natuurlijk het pad gewoon (...) Maar wat ik ook zie, daar, omdat ik, zeg maar, de route in m'n hoofd heb, hecht ik daar minder waar aan. Maar in het midden, zeg maar, om die hoek heen, daar zitten in het midden ook wel wat details. Er staat iets langwerpigs met uitsteksel naar de binnenrand van de hoek, zeg maar. (...) Als ik met m'n stok loop, had ik dat middenstuk niet gezien." This shows this perception of space triggers curiosity.

When talking about a space outside of his path that he 'explored', he describes that he could not know what it was that he saw in the map, because he did not get near enough to identify it. He points at the fact that he was not able to recognize what it was on the map:

"Het stuk waar je eigenlijk niet langskomt, dat daar ook details van te zien valt. (...) en ik weet niet wat het zijn, omdat ik ze niet letterlijk heb gezien. Dat is natuurlijk wel zo. Je kan niet helemaal tot in detail meteen zien wat iets is, zeg maar. Je weet het is een obstakel." When asked why he would want to know what these things are, he touches on an interesting point:

he describes how his spatial knowledge would enable a certain ‘spatial literacy’, that enables him to have more advanced conversations with other traffic participants than he would normally have, without this spatial overview: “Nou ja, dat kan helpen bijvoorbeeld om, zeg maar, te zorgen dat je als je gewoon een beetje de weg kwijt bent, ondanks dat je wel goed de kaart gebruikt, dat je ook bijvoorbeeld een voorbijgang even kan aanspreken van: ik ben eigenlijk naar dit en dit op zoek, waar zit dat, zeg maar? Stel je voor dat het een terrasje is, dat je weet van oh, ik moet om het terras heen, zeg maar. (...) Om je heen, zegmaar, heb je natuurlijk herkenningspunten nodig om te weten waar je bent, zeg maar.”

Upon asking him if he would want to be able to perceive space that beyond his route, het explains:

“dat kan je, als je vaker komt, dan kan je dat wel als herkenning gebruiken van, oh, daar in het midden zit wel iets, zeg maar.”

MENTAL EFFORT OF THE NEW MODE OF SPATIAL THINKING

This new way of thinking does take a lot of mental energy, because it is a whole new way of thinking and wayfinding. Efforts must be made to make the environmental perception as natural and intuitive as possible, so the user can quickly perceive a comprehensive overview of their environment.

P3 explains how he is not used to navigating based on spatial awareness of the environment, and the mental effort that this costs:

“Ik merkte toen we ermee bezig waren hoeveel energie het mij kostte. (...) 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.” He continues to explain that learning to walk with the cane also costs energy and that the added benefit of the environmental overview makes mobility easier: “[when you would have this product in real life] dat je dan daarmee in staat bent om efficiënter te navigeren. Omdat je dus, wat ik net al noemde, dat grotere beeld van je omgeving hebt. Maar het kost nu nog heel veel energie. Als je dat heel vaak zou gebruiken en je zou door die leercurve heen zijn, dan zou het… Stel dat het net zoveel energie kost als stoklopen en je hebt hier wel meer informatie mee, dan zou dat het navigeren makkelijker maken.” (P3 eindinterview)

1.2.2 SCALE AND DETAIL: OVERVIEW VS PRECISION

Due to the low detail of the map, participants had to choose between having an overview of the whole space, and accurate perception of movement. To switch between these modes, their maps could be zoomed in and out.

At the beginning of the route, P3's map is zoomed in and out, and he is asked which he prefers: the more detailed zoomed-in view or the broader overview of the zoomed-out map. He states his preference for the zoomed-out map as it allows him to survey the larger space. However, he adds that this overview comes with a trade-off, requiring more effort from him in terms of movement due to the reduced precision in his spatial perception:

"Ja, dan denk ik dat ik uitgezoomd wel prettiger vind. Gezien je dan, je moet al echt wat meer moeite doen. Alleen je hebt wel veel meer overal overzicht."

When asked how the zoomed in and out maps relate to each other, he responds:

"de herkenningspunten van de ingezoomde kaart, dat zijn de muur rechts van mij en een obstakel voor me, die zijn er nog steeds, hier, met als verschil dat je in de uitgezoomde weergave ook het hele stuk links en voor me er ineens bij krijgt, als het ware."

P3 explains that zooming out allows him to understand the space, understand where he is and how he can move through the space:

"ik ben benieuwd wat er gebeurt als je straks uitzoomt. Want wat ik nu zie, is eigenlijk gewoon: Kun je hier lopen, ja of nee? Meer zie ik nu niet, en ik denk dat dat deels komt door de resolutie van de dotpad, die niet superhoog is, je hebt maar een beperkt aantal puntjes wat je kan weergeven. Maar ik ben benieuwd, als je inderdaad uitzoomt, of het dan [makkelijker is om een overzicht van je omgeving te krijgen en jezelf te orienteren]". I then zoom out his map to show the whole room. yes explains that this view is much more useful because now instead of only being able to preview his path during movement, he can plan a route ahead: "Ja, oké. Kijk, dit is anders. Nu ben ik even benieuwd of dat klopt. Ik denk dat dit, wat ik hier voel, de muur aan de andere kant is. Is dat zo of niet? Dus dat betekent dat, zeg maar dit blok, deze hoek, is je obstakel, als het ware. Dus moet ik hier rechtdoor om dat blok heen om uiteindelijk bij deze muur uit te komen. (...) ik ben nu hier. Ik wil uiteindelijk ergens in deze muur zal de deur zitten. Dus ik moet rechtdoor, om dat blok heen, naar de muur. Is dat logisch?… wat je merkt, nu je bent uitgezoomd, krijg je dus in plaats van dat ik alleen maar kan beantwoorden: is het voor me vrij, ja of nee? Kan ik ineens zeggen: ik ga deze route lopen. Ineens kan ik zeggen, ik ga dit stuk rechtdoor, waar dat blok ophoudt, ga ik rechtsaf."

At a certain moment, P3 confuses his orientation. his map is very zoomed in and only shows the current path. he explains that this view is not able to let him Orient because he cannot see the larger environment:

"Volgens mij, en nu is het even lastig omdat we zo vaak zijn omgedraaid maar volgens mij zijn we nu weer ongeveer bij de tafel. Nou, dat is niet helemaal waar trouwens, maar we zijn nu weer waar we begonnen ongeveer, toch? Ja, en dat is dus, en dit is heel grappig, want hier zie je dus waar het misgaat als je een blinde laat oriënteren. Doordat we meerdere keren rondjes zijn gedraaid ben ik mijn oriëntatie kwijt en als we nu weer zouden zijn waar we zouden begonnen dan zou ik ongeveer dezelfde route die ik net met de stok liep weer proberen te reproducen, zeg maar. Maar dat lukt me

nu niet, doordat we zo vaak zijn rondgedraaid en ik dus geen oriëntatie meer heb van waar ten opzichte van de dingen. Misschien is dat juist wel goed, want dat is de echte test, maar dat zul je denk ik met de testers ook zien: Want sommigen die hebben echt een fucking goed oriëntatievermogen. Die kun je tien keer ronddraaien, maar als je mij aan mijn arm door de ruimte trekt of drie keer laat ronddraaien dan ben ik mijn oriëntatie kwijt."

When asked how the map could help him with maintaining his orientation, he explained that the ability to recognize the environment in the map would allow him to Orient based on the map:

"Ja, dat vind ik een lastige. Want de kaart die vertelt me nu vooral: waar kun je lopen, ja of nee? (...) De kaart vertelt mij niet het verschil tussen een obstakel en de deur. Dus als de kaart bijvoorbeeld een bepaalde icoon of een bepaalde structuur zou hebben voor een deur, dan zou je weten, dat is waar ik naartoe wil. Dan zou je je route kunnen uitstippelen, dat kan nu eigenlijk niet. Het enige wat ik nu weet is: ik kan rechtdoor lopen. Ik kan niet naar links en ik kan ook niet naar rechts. Dat is het enige wat de kaart me nu aan info geeft."

While standing in the middel of a large open space, P2's map is zoomed in so far, that he almost loses all the walls around him. He notes that

"Zoomen is echt heel verwarrend: Kijk, en nu, richting de kroegdeur zal ik maar zeggen, zie ik geeneens een muur meer."

It can be seen that he directly understands that the map is being zoomed in, however, it still is confusing to him because he now loses the context.

P2 explains how he recognized the wrong element in the map as his destination because he lacked the conte of the spatial layout around this element due to the map being too far zoomed in:

"Nou, je oriënteert je natuurlijk altijd op die randen. Ik dacht, op een gegeven moment, dat was wel leuk. Ik had een keer het kroegpunt laten zien, als er zat een gaping in de puntjes, alsof het een soort open ruimte was. Dus ik dacht: dat is een makkelijk oriëntatiepunt. En ik was helemaal de muziek vergeten, dus ik ging gelijk naar die plek waar dat fenomeen zich voordeed. "

However, what he had recognized as his destination was in reality a trash can, and he ended up in the wrong corner of the room, even though his end-goal was recognizable through music that was played through a speaker that stood in this location:

"nou ik had het nog niet gelijk als ik had in ieder geval onthouden dat het zo aanvoelde bij een bepaalde zoen en ja daar stond ik te zien in plaats van muziek te letten"

When asked why he could not use the conte of the spatial layout around the trash can to determine that this was not his destination, he explains that he was not able to see the conte because he was zoomed in:

"omdat dat nou precies is wat er verloren gaat bij zoemen ja maar dus kwam het omdat ik daar ook net voor dat moment in was gezoend. ik denk dat ik het anders eerder gezien zou hebben, want ik wist wel dat het in die linker hoek was ja dus weet niet of ik er aan gedacht zou hebben ook om dat maar in ieder geval hielp het zoomen daar niet bij. Dan krijg je steeds minder beeld van de ruimte van de kamer."

P2 explains how he prefers a larger overview, but shifts in his mind between different mental scales and also requires accuracy for movement through the path:

“als je denkt aan het voorbeeld van het park dan wil ik een flinke zoom (here, he means a large overview) hebben want ik weet dat er paden zijn en ben ik er nou weer voorbij gelopen ja of nee? Ik wil veel paden kunnen zien. Maar op het moment dat ik dan weer gaan lopen, dan ben ik in mijn onmiddellijke omgeving geïnteresseerd. (...) en dan op dat moment wordt het interessant hoe ik ten opzichte van het pad ben. Je schuift ook met die met die mate in je gedachte”

P2 explains that he lost his orientation due to the map being too far zoomed in:

“Ik vind niet dat het aan de kaart lag, maar aan het zoomen, maar hij heeft me dus niet geholpen om de kroeg te vinden in de tweede route. Maar dat ligt ook aan mij. Ik had ook best kunnen bedenken van: “Ik was toch in de linkerhoek?” Maar ja, dan vertrouwde ik mezelf niet meer, helemaal meer naar rechts, ja, oké. Maar dat is wel grappig, dus hij had... maar dus dat is natuurlijk altijd ook een deel: wat begrijp jij, en wat laat het ding zien?”

When zooming out P7 ’s map, he starts to recognize elements in the environment that he earlier encountered:

“Ja, dan zie je wel dat het die schuine hoeken daar… Linksvoor, die is wel een beetje kleiner nu. Maar dit voel je wel… Oh, hier is dat blokje. Oké. En is dit hier de pilaar? Oké.”

When playing with the zoom level, P7 explains that he prefers an overview, because he does not want to lose the context of the environment:

“nu is die veel te veel ingezoomd, wat dan, want ik ga hier nu naar links, ja, dan weet ik dat daar nog een extra straatje is, en dan nog eentje, ja, en nu voel ik, nu voel ik dat niet meer, want nu ben je veel te veel ingezoomd. (...) want in principe, in mijn mentale kaart, weet ik: (...) er zit nog zo’n tussenstukje die ik niet moet nemen, zo’n afslagje, en die wil je wel even voelen weer nu, op de kaart, ja, oke, even kijken, oh, je zei wel dat, ja, ik ging zo nog even iets uit”

P4 says that for an overview of the room, he would want to be able to see an overview of the whole room:

“Echt het overzicht van de ruimte blijft natuurlijk lastig, omdat je niet meteen de hele ruimte in beeld hebt.”

P1 explains how he want to use the overview of the environment interchangeably with a more accurate perception of his movement:

“ik denk dat ik gewoon wel wat af zou wisselen. Ik zou in eerste instantie, als ik daar sta, het overzicht bekijken, uitgezoomd van, goh, hoe zie ik mijn kaart nou uit? Ik wil daarheen. En vervolgens als ik dat heb, dan zou ik hem inzoomen om te zorgen dat mijn pad binnen zoveel meter, dat dat duidelijker is, en ik zou dan gewoon onder zoveel meter even uitzoomen van, zit ik nog goed ten opzichte van? Ligt er ook een beetje aan hoeveel bochten er in zitten, en stel je voor dat er best veel bochten in zitten, zou ik vaker uitzoomen dan niet, zeg maar.” When asked why many turns result in him wanting to consult the larger overview more often: “Nou, omdat je dan nog, tenminste, ik zou er dan nog wel een beetje in de war van kunnen raken of ik wel goed nog zit, zeg maar. (...) Ten opzichte van de kaart, zeg maar, want ik wil dan in mijn hoofd weer hebben, eigenlijk een beeld in mijn hoofd tekenen van, goh, ik sta hier ten opzichte van de kaart en ik moet hierheen.“

P7 is trying to find a way through the space in front of him, and he asks to zoom in on the route. When he is satisfied with the extra detail in the map, he determines a route and starts moving.

The map's limited resolution enabled a narrow scale spectrum per zoom level. Participants typically opted for a wider context, prioritizing overall view over detailed short-distance perception. There is a need for maps with greater precision without compromising the bigger picture. An enhanced interface should present a map rich in detail to facilitate accurate navigation while maintaining an overview. Given the limits of finger sensitivity, zooming remains essential and should be aligned with the mental process/scale.

P2 shows that when he has more detail, i.e. because he is further zoomed in, he is able to recognize environmental elements succesfully based on their shape:

"ik zie het nu echt heel anders. Links van mij zie ik die muur, zeg maar. Omdat het natuurlijk ingezoomd is, dan lijkt het of er een veel groter vlak natuurlijk is. En ik zie, zeg maar, de overkant van de muur zie ik nu niet. Ik zie wel wat er rechts van me zit, zeg maar. En ja, nu zie ik dus wel de pilaar." When asked why he does recognize it now, he replies: "Nou, omdat-ie net anders staat. Want je hebt hier zeg maar het obstakelding, wat rechts loopt, meeloopt, zeg maar. En dan ga je dat bochtje om, en daar zit die pilaar ergens. Je ziet dat dat wat massiever is."

1.3 CONCLUSION

The spatial perception allows participants to orient, but they need to be able to recognize the environmental elements for this, to be able to use as landmarks. This binary display enabled them in some cases to already recognize certain elements. They could use these landmarks to know where they are, which direction they were facing, and where they wanted to go.

However, in most cases it was insufficient to let the participants set and use landmarks in the environment. For example, participants were not able to recognize their goal in the environment. This made that they could use the map and its provided spatial layout to plan a route, however, the location within the map that they were headed towards was a guess. When they had extra directional information in the real environment, in the case of this experiment music playing at the location of their destination, they were able to determine the position of their destination in the map and, subsequently, their path towards it. It should be noted that in real life, the environment often contains such extra information.

An improved interface should provide a richer, more meaningful perception that enables users to recognize and understand the environment through a more detailed environmental representation and a more 'vivid' (i.e. non-binary) interface.

2 MOVEMENT WITH OVERVIEW

2.1 MOVING WITH THE ENVIRONMENT

Clear signs are seen of using the environment's movement to calibrate own movement. However the inability to directly perceive the movement makes this difficult with the current prototype, and requires the participants to stand till every now and then.

It is seen that participants regularly stop during movement to allow the map to refresh and to reassess their location to be able to understand how far they have moved along the path: it becomes visible how they use the movement of the movement of their environment to constantly re-orient and grasp the scale of and distances in the map. They explain how the slow refresh rate inhibits the their ability to perform this constant orientation during movement.However given an improved interfaces ability to clearly and accurately display this movement, this reorientation process would be possible during movement.

P3 shows how he tracks a turn in the path during his movement and uses its movement on screen to steer around it. he also explains how he combines this perception with his auditive perception, to fine-tune his movement.

"Ik wacht opnieuw weer totdat het obstakel rechts van mij weg is. Wetende dat ik nu langzaam bij de muur kom, dat hoor ik ook. (...) Oké, nu gaan we naar rechts. Want dat is wat ik van tevoren had bedacht. Ik wacht nu weer op de refresh om te kijken of dat inderdaad klopt. Nou, dat klopt."

P3 shows how he tracks the edge of the wall ne to him to determine when he can turn right.

He explains that this is difficult due to the slow refresh rate, which forces him to move slowly: "

En nu moet ik dus op de een of andere manier achterhalen. En daarom moet ik dus veel langzamer lopen, omdat ik ook niet weet hoe snel hij refresht. Ik zie dit obstakel als het ware kleiner worden. En als dit obstakel zo weg is, rechts van mij, dan moet ik ergens naar rechts.

When asked based on what he concludes this, he answers:

"Dat het vrij is. Dat ik hier een lege streep zie en dit ongeveer het midden is.

P3 explains his preview in his path, and how he plans to turn right as soon as the path turns:

"In theorie zou ik ook, het lijkt me logisch om rechtdoor te lopen, vervolgens naar rechts te gaan om het obstakel heen. En dan waarschijnlijk weer naar rechts, maar tegen die tijd zal ik even opnieuw moeten kijken. Misschien dat je ook, dat kan ik hier net niet helemaal lekker zien, misschien dat je ook nu meteen naar rechts zou kunnen. En dan via de rechterkant hier om dit obstakel rechts heen, maar dat kan ik niet goed inschatten. (...) Dan gaan we nu naar voren en ik wacht tot het obstakel rechts van mij, als het ware, kleiner is geworden."

When asked to explain his plan, he explains:

"Ik wil zo meteen naar rechts. Ik kan pas naar rechts als het obstakel rechts van mij voorbij is. Ik wacht dus, nou dat is ongeveer nu zo'n

beetje, nu zie je nog één streepje van het obstakel. Ik neem aan dat als ik nog één stap naar voren ga, dat dat weg is, grofweg. En dat ik in theorie - het probleem is dat hij nu een beetje onduidelijk is voor mij, want ik moet ook niet te laat naar rechts. -

Maar nu heb ik dus eigenlijk gewacht totdat het obstakel rechts van mij verdwenen is van het scherm, wetende dat zodra het obstakel verdwenen is, ik naar rechts toe kan. Want dan is daar vrij geworden."

P2 geeft aan dat hij goed door het pad weet te lopen met het prototype:

"Ik kan hier de gidslijn goed op voelen, en ik kan ook voelen waar ik zelf ben."

P2 explains his technique to walk through the environment based on the perceived motion, by keeping his self marker accurately within the path. although this process happens slowly due to the low refresh rate, he is observed making accurate decisions about his location within the path, and subsequently taking action to readjust his movement:

"... eigen aanwijspeiltje, hou ik dus op het vrije pad." It is observed that he steers a bit to the left. Upon asking him why, he says: "Nou, ik was behoorlijk dicht bij de linkerkant volgens deze kaart."

Later, he explains the same technique again and how he uses this accurate orientation in combination with his overview of the larger space to move towards an open space in the environment: "Ik ben bezig om mezelf vrij van de buurt te houden en op de grote ruimte uit te komen. (...) Dus ik probeer mijn aanwijspijltje, zal ik maar zeggen, recht naar het vrije stuk te krijgen."

P2 explains how he can use the 'free path' for his movement: "Wat ik heel leuk vond, is dat je vrij pad kunt herkennen." When asked how he perceives this, he responds: "Nou, ik zie mijn eigen pijltje, zal ik maar zeggen. En ja, als er vrije ruimte voor me is, dan zie ik dat. En ik zie ook dat de afstand is tot de rand, dus dat geeft ook nog enige ondersteuning."

P5 describes how the ability to feel the environment move underneath his fingers would make movement based on the map much easier:

"De route die zou je goed kunnen lopen, wat ik moeilijk vond is dat eigenlijk de puntjes voor mij dus niet beweren. Als ik zou lopen en de puntjes zouden omhoog gaan en je daar zou stoppen en je kan dan de hoek omgaan, dan zou het denk ik een stuk makkelijker voor me zijn. Dan zou ik met de puntjes mee kunnen lopen, dus je loopt en dan voel je de puntjes omhoog gaan en dan houd ik op zodra je de hoek omgaat."

P1 explains that the ability to directly perceive real-time movement is required to move effectively and safely with the device:

"Die verversingssnelheid moet echt wel optimaal zijn, hè. (...) realtime moet je weten waar je zit. Als het te lang duurt, als jij moet gaan wachten tot iets gerefreshd is, dan kan je nog wel eens ergens tegenaan lopen..

He turns around precisely, feels the map and quickly finds his way through the narrowing of the path:

"Ik ga hier naar links, dan kan ik even een paar meter lopen en dan weer naar rechts."

P7 uses his movement to understand the distance of the wall based on its movement towards him as he walks forward. However, at first, he notes that he does not feel the wall nearing him. This is due to the screen's inability to refresh underneath his fingers:

“Wat voor mij is, ik kan natuurlijk mijn vingers nu voelen, ik heb twee handen, links en rechts, voel ik natuurlijk hoe die straat loopt en waar hij dan naar rechts gaat, wat bij mij dan de vraag natuurlijk is van hoeveel kan ik er nu vooruit lopen, dat je eigenlijk de schaal niet weet. Want ik kan nu wat schatten van tussen mijn twee vingers, boven en onder, dat zijn misschien acht centimeter. (...) Als ik nu vooruit loop, ja, dan zou je misschien, kijk als ik nu vooruit loop en ik voel de bovenkant, zou ik misschien verwachten dat dan die muur dichter bij me komt, maar dat is eigenlijk niet zo, die muur blijft hier staan.”

He lifts his fingers, the screen refreshes, and he notices the wall has come closer:

“maar ik ga weer even een halve meter naar voren, en nu weet ik dat ik mijn handen weg moet doen. Oh ja, dit is een beetje kleiner geworden, dus ik denk dat ik hier nu zo de bocht in kan.”

This example shows a clear example of the usage of the movement of the environment in the map for dynamic orientation during movement.

P7 stands in front of a small corridor. He uses the map to precisely align his heading with the path and stand right in front of it:

“ik denk dat ik hier nog steeds wel schuin sta, wacht hoor, ik ga even mijn karretje een beetje meer zo zetten. Ja, dit is beter, maar ik wel, nee ik denk dat ik een beetje, wacht, ik moet weer die route doen, oké.”

He explains his need for the ability to perceive the wall approaching in real-time, which was not possible due to the screen’s low refresh rate:

“wat misschien handig zou kunnen zijn, is als je een meter van de muur staat, dat dat ding gaat trillen ofzo, ja, of dat je misschien een akoestisch ding hebt van piep, hé hier zit een muur van de muur, ja, want dan kun je gewoon doorlopen (...) omdat je dan nog net tijd genoeg hebt om te stoppen”

P7 legt uit dat hij de beweging op de tablet wil kunnen houden en de beweging kunnen voelen, zodat hij soepeler kan doorlopen, in plaats van in horten en stoten:

“het is wel even wennen van ik zit met mijn vingers op dat pijltje, en opeens staan er puntjes vlakbij mij, dus hier kan ik dus niet door. (...) je moet natuurlijk je vingers afhalen van dat ding wegdoen voor de refresh. Ik ben benieuwd hoe dat je het heel soepel kan doen, dat je kan blijven doorlopen en dat je dan in één keer maakt, oh die puntjes komen dichterbij, dus ik moet een beetje naar rechts. (...) [om soepel te kunnen doorlopen heb je nodig] dat je je handen op de tablet kan blijven houden.”

He explains that this would also enable a more passive environmental perception strategy:

“stel dat je, stel dat je, weet je, net zoals dat je als blinde een beetje zo je handen voor je houdt. Ja. Dan kun je natuurlijk ook je handen op die tablet houden. En stel dat je dan loopt en op één keer voel je bij pink puntjes komen, weet je van, oh, hier is een obstakel, dus ik moet een beetje meer naar rechts.”

Is is observed that P3 steers off the center line of the path:

“Ja, dat komt doordat je geen oriëntatiepunt hebt. (...) Hoe lopen ziende mensen recht door een ruimte heen? Door met hun ogen ergens op te focussen. Als je blind bent, moet je dat doen door ofwel fysiek iets in de ruimte te volgen, een randje, de rand van de stoep ofzo. Ofwel, ja, niet.”

When asked how he does this now, with the prototype, he explains that he would need a higher refresh rate to be able to track the environment and maintain a heading while moving:

"Ik denk dat je dat pas krijgt als je een veel hogere refresh rate hebt. Want nu kun je eigenlijk de output van de dotpad alleen gebruiken als je stil staat."

P3 over lopen met vooruitzicht, doordat je al van tevoren kunt weten welke obstakels er gaan zijn: "Je kan denk ik met oefening [ten opzichte van de stok] meer in staat zijn om schuiner te lopen omdat je, zeker als die refresh rate hoger wordt, makkelijker kan voelen: "oh, welke obstakels gaan er zijn?"

P2 is standing in the middle of a relatively large open space, with out any environmental elements near him that he can use for his orientation. when asked if he knows where he is within the space he explains how he uses the far away boundaries of the space to move through it. Interesting to see is that he understands that he needs to turn slightly to the left to reach move in a straight line towards his goal, because he perceives its location in the map slightly to the left of the center line, indicating that he successfully uses the DTM for maintaining a heading in open space:

"Nou ja, omdat ik de kaart gezien heb. Het was een makkelijke kaart voor mij in het begin. Dus ik weet nu, ik zie nu de muur van de vrije ruimte langzaam op me afkomen. En ik moet nog wat meer naar links. (P2 experiment)

When asked how well aware he is of the distance this goal is from him (the map was zoomed in and out a couple of times, so he had no reference from earlier knowledge of the map's zoom), he replies:

"Ik beweeg nu zo langzaam. Dat ik aan mijn beweging geen oriëntatie meer heb."

What he explains here, is that the slow refresh rate and the relatively small movement of the map due to his slow movement speed makes it difficult to translate the distance of the goal on the map to a real-world distance. This indicates his strategy to use the approaching speed of the wall in front of him to understand how far this wall is still away from him.

P3 explains how he currently used the device to use his regular walking method, the guideline, but from a distance, which shows how the prototype allows for the use of similar walking strategies: "Ik dacht eerst dat ik heel erg anders zou gaan lopen. Dat valt wel mee eigenlijk. Met een stok zou ik de rand volgen van het obstakel totdat het ophoudt en dan zou ik er omheen gaan. Maar eigenlijk deed ik dat met deze technologie ook."

He continues to explain how this device however could free him from the guideline and enable a different walking strategy:

"[the device would enable you to walk] meer schuin en recht door de ruimte, omdat strikt de randen van de obstakels volgen is niet altijd de kortste weg."

when asked why he did not do this in the experiment, he responds: "Omdat de obstakels in een vrij rechte lijn stonden voelde het logisch om daar dan omheen te lopen. En omdat schuin, het is best lastig om recht door een ruimte te lopen zonder dat je met je ogen ergens op kan focussen. En als je dan schuin door een ruimte gaat lopen zonder reference point dan is dat heel lastig. En dat is ook als je vanaf een beginpunt staat en je ziet dat het voor je een ruimte is en links kan niet, rechts kan niet, dan ga je toch maar naar voren. Dus dan volg je toch maar de lijn van het obstakel. Terwijl het misschien ook wel mogelijk was om schuin te lopen. Maar als je blind bent ben je ook niet gewend om schuin te lopen. Dat is ongeveer het eerste wat je leert: Loop altijd in een rechte lijn, loop nooit schuin.

When asked how, in his experience, this device could aid this alternative strategy, he replies: “Nou door wat ik net zei, je stok geeft je maar anderhalve meter ruimte, nog niet eens, deze technologie geeft je een paar meter ruimte, dus je kan denk ik met oefening meer in staat zijn om schuiner te lopen omdat je, zeker als die refresh rate hoger wordt, makkelijker kan voelen welke obstakels schaander zijn.”

He continues to explain that the slow refresh rate of the prototype was the most important factor for him not using this strategy: “Als je loopt en daarna ga je stilstaan om te kijken of je wat je in je hoofd had inderdaad hebt uitgevoerd. Dus of je inderdaad echt bent gelopen, hoever je nog moet tot het obstakel of tot je een bocht moet maken. Dan ben je dus heel lang aan het wachten op die refresh rate.”

P1 describes how he uses the movement of space in the map to steer his movement: “Dit helpt zo ook om te weten of je scheef loopt, want de hele kaart gaat al scheef.”

P7 shows his understanding of his own rotation within the map and relative location of his goal: “Ik sta weer een beetje schuin, ik sta niet in hoeken van 90 graden.(...) Nou dat is de vraag van of ik die hoek mee kan krijgen, dat ik hier dan, als ik nu helemaal draai.”

P3 Experiment, X - P3 mentions that he is unsure how far he has to move to the right to go around the obstacle because at this stage, there was no self-marker, let alone an indication of his own skill within the map. this made it difficult to steer accurately around the obstacle without bumping into it: “En nu neem ik aan dat ik rechtdoor kan lopen, precies tussen deze twee dingen door. Ik denk dat dit wat je links hier hebt, zal die muur zijn, links van mij. Wat ik dan even lastig vind, is of ik nu ect rechtdoor kan lopen, of dat ik iets naar rechts moet.”

When asked what he uses in the map for his orientation, he replies: “Deze zijkanten, dus ik probeer mijn aanwijspijltje, zal ik maar zeggen, recht naar het vrije stuk te krijgen.Ik zie hier dat er nog een heel klein stukje muur is, en dan beginnen we in de vrije ruimte te komen.

He now enters open space, he has no reference of nearby walls or boundaries of the path. When asked where he is and where is goal is relative to him, he successfully points out his goal on the map, and in his real environment, indicating that he successfully translated the location of his goal on the map to a real-world location.

2.2 PREVIEW IN THE PATH AND REDUCTION OF VIGILANCE

2.2.1 ANTICIPATION

This spatial overview can be used to anticipate obstacles and turns in the direct path for movement

P3 uses his preview in the path ahead to anticipate and steer around an obstacle that is still a couple of meters ahead of him: “Eigenlijk direct voor mij, rechts moet obstakels zijn, dus ik denk dat ik iets naar links moet, en dan weer naar voren kan.”

When asked to explain what P3 knows about his environment which he uses for his own plan of movement he shows that he has a clear overview of the environment that is still a couple of meters and around him: “Rechts, zeg maar direct rechts van mij, obstakel, dat is zometeen, over een paar meter is dat voorbij. En voor me is het ook nog steeds vrij. En links, wat verder weg is ook een obstakel. (...) Dit is obstakel, dat is dit ding. Dus ik kan, denk ik zometeen, als ik hier voorbij ben, kan ik naar rechts. En ik kan verder naar voren.”

P3 explains the alerness: “… als je een geleidehond hebt, dan kun je letterlijk gewoon achter die hond aanlopen voor je immediate surroundings, je directe omgeving, waardoor je met je oren en met je gedachten bij de grotere omgeving kan zijn. Terwijl als je met een stok loopt zijn je gedachten zo erg opgeslokt door die directe omgeving en je eigen veiligheid dat je verder ook nergens over nadenkt.” - Maar dat opgeslokt zijn door je directe omgeving en je eigen veiligheid, had je dat hier dan niet nodig? - “Minder. Omdat je range die je eigenlijk hebt groter is, dus je kan dingen van verder zien aankomen. Nu nog niet altijd vanwege die refresh rate soms, maar ik geloof dat als je die refresh rate hoger krijgt, (...) dan kun je dingen veel eerder zien aankomen, terwijl met je stok zie je ze pas aankomen als je ertegenaan loopt.”

2.2.2 LIMITED BY REFRESH RATE

However, the relatively long time it took to refresh limited the ability to maintain an overview during movement and successfully identify and anticipate obstacles during movement.

P4 legt uit dat je sneller kunt lopen doordat je kunt anticiperen: “in principe, als je dit realtime zou doen, dan zou ik hier vrij snel, als het echt betrouwbaar zou zijn, denk ik, dat ik hiermee heel snel door de ruimtes zou kunnen navigeren. (...) Omdat ik met een vrij grote zekerheid voel (...) dat ik niet ergens tegenaan ga knallen. Het leuke hiervan is natuurlijk wel dat het ook wat verder gaat in die zin dan een stok. Want een stok gaat natuurlijk maximaal twee meter. Als je dit goed laat werken, dan zou je dus ook die enorme gang lopen en op tijd, misschien wel een paar meter van te voren, kunnen voelen dat de trap (...) dat die eraan komt.”

He continues to explain the preview in the path and the benefit compared to obstacle detection technology:

“het probleem met een gewone obstakeldetector (...) is altijd dat je alleen maar een trillingtje voelt. Dat zegt dus helemaal niks. Je weet niet wat het is, je weet niet waar het is. En met deze oplossing weet je ook nog niet wát het is, maar in ieder geval wel wáár het is en ook zelfs hoe groot het is.”

P4 explains that the preview that the device offers would allow you to walk faster, because you can see obstacles and hazards coming up from further away: “Het voordeel lijkt mij dat je inderdaad veel meer inzicht hebt in de ruimte, waar je bent, en dus ook wat meer vooruit kunt kijken. De beperking van een stok is het lijkt mij toch hij zit altijd maar twee meter voor je wat daarna komt. Ik denk ook dat de snelheid die je kan halen daarmee heel erg beperkt is. Ik kan me goed voorstellen dat je met zoiets als dit, als het echt betrouwbaar zou werken, relatief veilig ook een beetje, door kunt lopen."

Due to the slow refresh rate and the inability to constantly track movement, reading the screen costs a lot of time and effort. This limited the overview that participants were able to obtain during movement, causing them to occasionally miss obstacles in the path.

P3 addidentally walks past it and bumps into the wall in front of him. He explains that he was so focused on the wall ne to him, that was difficult to perceive due to the low refresh rate that he missed the wall in front of him: "Ik zat nu alleen maar te letten op dat andere obstakel, en dus niet op wat er voor me gebeurde. Is dat slim? Nee. Nu ga ik even wachten. En ik denk dat het vrij is."

P3 explains that due to the difficulty of this action, he lost his orientation. He cannot relocate his objective, because he cannot recognize it on the map: "Behalve dat ik nu door al dit geloop mijn oriëntatie mis van waar nou de muur is waar ik uiteindelijk heen wilde. Want vanuit waar ik net was, zal dat zo ergens links van mij zijn."

2.3 CONCLUSION

The current refresh rate and the DotPad's inability to refresh braille dots under a finger constrained the direct perception of movement, which is important for effective preview and anticipation during movement (e.g. feeling a wall approaching). This ability is important for the experience of overview and not worrying to miss something.

Map orientation: Confusion arose from the misalignment between map rotation and the real environment (due to a misalignment between the prototype and the participant's body). Participants expected the top-middle part of the map to be right in front of them, also when they were not standing exactly in front of the screen. Sensory overlap proved beneficial: locating a pillar using echolocation linked its map representation to its real-world position, clarifying any rotation of the map.
A mechanism that ensures a clear mental mapping of the map's front and the user's body is important to avoid confusion.

3 MENTAL TRANSLATION OF THE MAP

The map is a translation of the real environment. The user must ‘translate’ the perception through their fingers of the perceived map geometry to a mental image of the environment. This process costs cognitive effort and focus. The more natural and direct this perception, i.e. the less deliberate translation this costs, the more effortless the user can read the map and form a comprehensive, constant overview of the environment while moving around.

This section explains a couple of challenges inherent to perceiving the environment through a map translation.

3.1 RECOGNIZING SCALE AND DISTANCE IN THE MAP

Size of the space perceived in the map was difficult, because it was not directly perceptible. A scale reference, for example an indication of one’s own size within the environment, is mentioned as a good way to understand the size of the space and distances, and would greatly benefit accurate movement. A more intuitive understanding of scale could also be achieved through a standard zoom, that the map ‘wants to get back to’. The user can zoom in and out when they more detail or more overview.

P3 explains that he needs something to directly perceive the scale of the map (note that the prototype does not contain a scaling self-marker that shows the user’s size in the map: “Ik denk dat dat met name komt doordat je niet weet wat de schaal is van dit. Je weet niet of dit stuk van de dotpad, of dat betekent twee meter is vrij of tien meter is vrij. Eigenlijk zou je een soort schaal willen hebben.”

P2 describes that he would benefit from a standard zoom, to have a natural understanding of map scale and distances: “Als je veel met zo’n kaart zou lopen dan zou je weten hoe groot de zoom is en dan zou je -althans, dat zou ik doen- dan zou hem altijd op een standaard zoom zetten en zeggen: dat is mijn referentie, en pas als ik iets anders nodig heb en meer overzicht of juist minder overzicht nodig heb, dan [zou ik zoomen]. (...) Dus omdat je besef van afstand zo met die zoom samen hangt zou ik dus mezelf echt altijd bewust aanwennen om een standaard zoom te gebruiken totdat ik iets anders nodig heb”

“Nou eigenlijk was mijn gedachte vooral, oké, ik wil naar voren lopen. Dit is vrij rechtdoor, let’s go. Maar op een gegeven moment, ik weet niet wat de schaal hiervan is. Betekent dit dat ik twee meter kan lopen, dat ik tien meter kan lopen? Dat weet ik niet, dus op een gegeven moment stop ik om soort van maar af te wachten of het inderdaad nog steeds vrij is.”

P3 test the movement of the environment as a result of his own movement and explains how he understands it: “Want dit, waar ik nu mijn vingers op heb, dat zal denk ik de muur zijn voor mij. Of in ieder geval de… Ik weet niet of daar nog obstakels voor staan, maar… Want hierachter is niks meer, dus waarschijnlijk is dit het einde. Waarschijnlijk als ik achteruit ga… Ik neem aan dat ik nu… Ja, dit is nu verder weggegaan. En ik denk dat als ik dichterbij zou komen. (...) Nu is dit weer dichterbij gekomen, wat opzich logisch is”

3.1.1 MAP MOVEMENT FOR

DISTANCE UNDERSTANDING

Multiple participants made successful estimations of the space and distances through movement, but this was difficult due to the inability to directly perceive movement.

After comparing the movement of the map with his real-world movement, P7 is now able to deduce the distance in front of him through the map (he knows the zoom has not been altered): “De schaal, nu weet je hier, de vorige keer was die 8 centimeter, was nu 4 meter, om het zo te zeggen. Dus nu hebben we gedraaid, en nu heb ik hier nu een stuk van misschien 3 centimeter, 2 centimeter. Dus ik denk dat ik nu 1 of 2 meter vooruit moet, en dan kan ik naar rechts.”

This shows that through comparison of real-world movement and movement of the map, the scale of the map can be deduced.

3.2 TRANSLATING MAP SPACE TO THE REAL WORLD

The correlation between map directions and physical environment directions can sometimes be challenging and participants slightly overestimated the angle towards an element perceived in the map.

During the first minutes of the eosure to the DTM prototype, when asked to point at a cabinet that he successfully identified on the map, he overestimates the angle towards it, and points further to the right than it actually is: “Ik zie hier het kastje, dus het moet een klein beetje schuin vormen. Het zijn 45 graden ongeveer.”

P2 experiment - When asked to point in the direction of his end-goal, P2 shows how he maintains his heading and understanding of the relative location of his goal based on the map: “Ik denk daar ongeveer, dus die kant.” P2 points in the correct direction “Ik zie hier dat er nog een heel klein stukje muur is. En dan beginnen we in de vrije ruimte te komen.”

Another time, When asked to point at a specific element that he uses for a reference in the map, P2 points in the wrong direction: “Nou, hier. Ik zie hier het kastje, dus het moet een klein beetje schuin voor me zijn, 45 graden ongeveer.”

When asked to point in the direction of his goal on the map, P2 again overestimates the angle towards this element and points slightly past it: “Nou, het zou er dan daar moeten zijn, toch?”

While standing near his destination, P1 locates this through the music that is playing at that location. He explains that he would have expected the destination to be in a different location based on its location in the map: “Maar dan voor mijn gevoel is dat [de bar] daar dan zou zijn. (...) Ja, dit is de bar, zei jij. En dat zit een een beetje hier zo. Terwijl ik hoor de muziek daar vandaan.”

This indicates that the translation of map location to real-world location, and the resulting directions is still difficult for him.§

P1 is again confused about the map not displaying a pillar to his right: “Nou, die pilaar zie ik dus niet. (...) Rechts van mij. Links van mij wel, zeg maar. Maar rechts zit er wel wat, zeg maar. Maar rechts, die pakt hij niet. Maar misschien sta ik te schuin. Maar ik zou zeggen dat hij dat wel had kunnen pakken, zeg maar.”

It can be seen that although he is standing right next to the pillar, the map itself, the DotPad, is standing in front of it, and does not display the pillar, because it is behind it. This confusion happens because translation of the map frame to ‘his own frame’ is not natural to him.

Reactionary movement and rotation of the map felt unnatural. Perceiving the larger space’s relative movement due to one’s own movement and translation is, especially for the congenitally blind, an unaccustomed phenomenon. Natural understanding of the relative location of things perceived in the map is sometimes difficult due to the nature of the map and the need to cognitively translate these locations within the map to locations in the real world. However, when participants were instructed to orient the map towards a specific location, they managed to align themselves and the map accurately. In a dynamic situation where the user aims to walk directly towards something in the map, this could might not be a problem. However, the intuitive understanding of these directional mappings needs improvement. It's likely that with more experience, users will find this process increasingly natural and easier to grasp.

P2 explains that it cost him a lot of mental effort to process the perceived movement on the map as a result of his own movement and rotation: "omdat je steeds bewust moet zijn van wat er gebeurt denk bijvoorbeeld toen ik het vrije pad zorg dat ik spontaan toch de verkeerde kant op draaide ja wel het scherm het echt wel goed aangaf maar je moet even andersonder leren denken. (...) als je vooruit gelooft ja dan loop je vooruit dat voel je aan je lijf dat is je lichaamswaarneming maar op je kaart zie je dat de aarde achteruit schuift dus het is toch wel het is echt een fundamenteel punt"

P2 is confused about the direction he needs to turn to move through a narrowing of the path: "Nee, sorry, ik draai verkeerd. (...) ik wil er tussendoor, hè? Dus ik moet eventjes goed bedenken hoe ik loop. Dat is een typisch zo'n voorbeeld van egocentrisch en non-egocentrisch: Hoe moet ik nu draaien om mezelf in de goede richting te krijgen?"

Also, the current mechanism for awareness of one's own position within the map, through the self-location marker in the bottom center of the map, sometimes lead to confusion and a loss of self-location awareness. Multiple participants experienced difficulty finding back their self-marker and thus maintaining an awareness of their own location in the map and, consequently, relative locations of different elements perceived in the map.

P7 : "wat wel een probleem is, is om steeds dat pijltje weer te zoeken.

3.2.1 RELATIVE MOVEMENT OF THE ENVIRONMENT IS A VISUAL CONCEPT

Zooming is unnatural, and it mainly feels as if the 'space becomes larger'. These phenomena and the challenge of understanding the map's movement will require a learning curve that must be acknowledged. These phenomena are geometrically logical; when looking closer at something, it becomes larger. When moving forward in an environment, its geometry moves towards you, in opposite direction. These effects feel unnatural, as they happen inside a 2D top-view map, however, they are similar to their 3D counterparts in the real world. It is assumed that these phenomena simply take getting used to by the blind individual.

P2, who has been blind since a very young age, is asked how he experiences zooming in of the map. He finds this confusing, because it feels as if the space is getting larger. This reactional perceived movement of the walls around him (moving further away from him as the map zooms in) is a confusing concept which he does not naturally understand because he has never experienced a zooming map: "Wat is inzoomen en wat is uitzoomen? Volgens mij maak je het vrije pad om het zo maar te zeggen groter. (...) Ja, wacht even. Nou, je ziet, ik moet erover nadenken. (...) Ik had de beleving dat de wand, zal ik maar zeggen, bij me vandaan ging en kleiner werd. (...) Dat is mijn associatie, terwijl in werkelijkheid is die wand natuurlijk niet veranderd. Maar de details zijn beter zichtbaar geworden."

Later, his understanding is tested again. When asked what he notices when his map is zoomed in, he replies: "De vrije ruimte neemt weer toe, dus je bent aan het inzoomen. Ik zie hier nog een heel klein stukje muur, die is bijna in het oneindige verdwenen. (...) Zoomen is echt heel verwarrend."

P1 explains how he got used to the new way of thinking over time: "In eerste instantie ga je natuurlijk kijken van, hoe sta ik erop in opzicht op de kaart? En je gaat kijken, hoe snel gaat dat? En wat gebeurt er als ik een beetje meer die kant op ga, en je gaat een beetje spelen met, hoe word ik op de kaart weer gegeven? En op dat opzicht, dan kan je op een gegeven moment wel wat makkelijker en vertrouwder lopen, zeg maar."

3.3 EDGES OF THE SCREEN

Multiple participants struggled with understanding that the screen ends without a clear marking: The DotPad's screen is designed in such a way that it gives no clear clue of the screen's ending. This resulted in confusion, when environmental geometry suddenly seems to 'disappear'.

In an enhanced design, it is important to resolve the issue of screen boundaries. When utilizing a screen, it's essential to clearly communicate its limits. This way, participants will understand that environmental elements disappearing from the screen haven't vanished but have merely moved beyond the map's range.

3.4 SENSORY OVERLAP

Integratie met andere zintuigen helpt om betekenis toe te kennen in de kaart, waardoor je niet meer via de kaart hoeft te proberen te achterhalen wat iets is. Als je iets hoort, kun je het via de kaart direct localiseren. Deze samenwerking is gunstig voor intuïtieve omgevingswaarneming.

Het helpt ook om juist elementen op de kaart in fysieke omgeving te lokaliseren. Bijvoorbeeld als je een pilaar waarneemt op de kaart en je hoort hem via echolocatie, helpt dit om de draaiing van de map extra duidelijk te maken.

Integratie met andere zintuigen gebeurt voornamelijk met gehoor. Echolocatie wordt in het experiment regelmatig gebruikt ter verificatie van op de kaart waargenomen elementen, zoals pilaren in de ruimte. Gehoor wordt dus gebruikt in samenwerking met de kaart.

3.5 CONCLUSION

- Self-position awareness must be improved: Incorporate a mechanism to help maintain constant awareness of one's location while scanning the map.
- A better 'mapping' of direction would benefit the understanding or orientation and movement.
- To enable intuitive and fast map reading, participants must be able to easily and quickly scan the environment
- Ensure the map's movement and zooming features are intuitive and align with the tactile perception of VIPs. In this, consider the unique learning curve of VIPs in adapting to visual concepts like zooming and reverse movement.
- Sensory overload must be minimized: Balance detail and simplicity that reduce cognitive effort of processing the map to avoid overwhelming the user, especially in contexts requiring quick decision-making. It is important to keep in mind the varying mental scale.
- Sensory Integration: Enhance the sensory overlap, particularly between the map and auditory cues, to support a more holistic perception. Leverage other senses, such as echolocation, to complement and confirm the tactile map's information.
- Self-Position Awareness: Participants struggled to keep track of their own location on the map, leading to a lack of awareness about the position of perceived

elements relative to themselves in the real environment. This difficulty in identifying the relative position of perceived obstacles was due to the loss of self-position awareness, causing uncertainty and errors in movement. A more effective solution is needed to consistently maintain awareness of one's own position.

- Egocentric Representation as an unintuitive, visual concept: The reverse reactionary movement of the map and the effect of zoom on the map frame were challenging for participants. Further research is needed to understand how VIPs adapt to these visual concepts, but it is assumed that these logical concepts will become intuitive through use.
- Map orientation: Confusion arose from the misalignment between map rotation and the real environment (due to a misalignment between the prototype and the participant's body). Participants expected the top-middle part of the map to be right in front of them, also when they were not standing exactly in front of the screen. Sensory overlap proved beneficial: locating a pillar using echolocation linked its map representation to its real-world position, clarifying any rotation of the map. A mechanism that ensures a clear mental mapping of the map's front and the user's body is important to avoid confusion.

APPENDIX I OWI EXPERIMENT

The goal of this research and design process is to find and develop diverse roles and experiential qualities of an OWI that acts as a collaborative partner in the VI mobility process, extending beyond just functional advantages and creating a more engaging and interactive mobility experience.

The design phase and the established design vision lead to the identification of various roles and experiential qualities for the OWI. To explore the range of possibilities, the process begins with an ideation phase that focuses on generating many potential directions, roles, and interactions for the OwI. From this ideation process, a specific set of roles for the OwI is chosen. To delve deeper into these roles, explorative sessions are conducted with VIPs in a real-world setting. In these sessions, enactment and Ultra-Rapid-Prototyping are applied to investigate and further develop these different roles.

At the time of the experimentation, the functional prototype was incomplete due to the unavailability of the DotPad. This inhibited the exploration of the OWI functioning through the map. Attempts to simulate the Dynamic Tactile Map's effects with simpler tools were not successful, as these tools couldn't adequately convey the intended effect to participants. Consequently, the integration of OwI as an extension of the Dynamic Tactile Map couldn't be studied, and the research focused only on embodied interaction that did not depend on the DTM.

This research leads to the conceptual design of a collaboration between the OwI and the user through a physical push-pull language, where the OwI pushes the user away from potential hazards. Because of its embodied nature, this 'language' between user and OwI is a valuable addition to the environmental perception through the DTM, and an interesting interaction comes into existence, where participants used this cooperation as a further perceptive sense within their environment. For now, it is chosen to focus on this implementation of the Object with Intent, however the OwI could play many other roles and in this setting. These possibilities remain open for exploration in future research.

DESIGN IDEATION

Based on the design goal and vision, an ideation process is performed, that aims to potential roles for the Object with Intent.

Short recap of design implications:

- The grounding metaphor for my concept will be a map that helps you in your mobility.
- The tool shifts between merely a tool for perception and an agent/partner where it acts based on its own intentions. Sometimes the map is a passive tool, merely displaying the environment, and at other times, it would actively suggest or step in, turning into an active agent or partner.
- It is important to think about communication and Negotiation: Establishing a dialogue of intentions between the user and the Owl.
- Interaction with an Owl is direct rather than semantic. The Map with Intent should offer tangible, direct, physical feedback. In this project, I will aim to make this feedback as physical and embedded in the environment as possible. Due to the unavailability of the DotPad at the time of this experiment, I will focus on embodied interaction that is independent on the spatial perception through the Dynamic Tactile Map (DTM). In the experimentation, I thus look for an embodied or direct interaction that takes place within and with relation to the environment. This involves different interaction styles, such as pointing the user towards environmental elements, pushing and pulling the user and providing haptic signals that are directional and intensify or otherwise change when nearing an environmental element (Note that due to the explorative nature of this experiment, interaction Styles are expected to arise on the spot).
- The device should be transparent about its decision-making process to ensure trust calibration.

RESULTING DESIGN

From the design goal, it is decided that the Object with Intent can play a role in improving environmental awareness, reducing the need for vigilance and increasing experience and engagement with the environment and exploration of the world. This leads to various different roles with their own experiential qualities and interactions for the Object with Intent:

The ideation process arrives at two potential directions to be explored in the experiments:

- The curious, explorative partner who wants to experience the environment with you and encourage engagement.
- The observant partner who keeps an eye out for your safety so you don’t have to. In this role, the Owl watches with you and wants to keep you away from danger.

EXPERIMENT SETUP

Explorative Sessions: Conducting sessions with VIPs using wizard-of-oz like enactment and Ultra-Rapid-Prototyping to refine the Owl's roles. I learn about interactions through reenactment and co-creation of intelligence and using an artifact and come to inspiration for an active partner in mobility.

Participants: The experiment is carried out with 4 fully blind VIPs in a realistic, outside context, anonymized for privacy reasons.

Different implementations of the different roles are tried in the experiment:

- The curious, explorative partner who wants to experience the environment with you and encourage engagement.
  - It explains the surroundings upon request, highlighting points of interest and potential destinations.
  - The Owl suggests possible routes, allowing the user to choose their path by indicating a direction.
  - It shows the user that there are places to go and helps guide them towards specific waypoints or goals.
  - The system can provide subtle resistance (a light pull back) to indicate a denial or rejection of a chosen path.
- The observant partner who keeps an eye out for your safety so you don't have to. In this role, the Owl watches with you and wants to keep you away from danger.
  - It alerts the user to obstacles and dangers while walking, and actively steers them away from hazards, edges of paths, and roads.
  - The system guides the user along safe paths, avoiding obstacles and ensuring they stay off dangerous routes like roads.
  - The Owl uses varying intensities of pushing or pulling to communicate with the user, and can override user decisions if necessary for safety. This push and pull forms a negotiation where the user and object can pull back and forth to 'overrule' each other's intentions
  - Tempo changes: slowing down in narrow or tricky situations where more caution is needed, and speeding up when the path is clear and safe.

RESULTS

1 EXPLORATIVE PARTNER

In this role, my goal as Owl was to help user understand what the environment around them looks like and what they can do there and to encourage them to take exploratory routes. Different types of interactions were explored:

1.1 DIRECTIONAL PULL TO HIGHLIGHT ELEMENTS IN THE ENVIRONMENT

- The Owl explains the surroundings upon request, highlighting points of interest and potential destinations. It shows the user that there are places to go and helps guide them towards specific waypoints or goals.

In this part of the experiment, participants were tasked to actively use the Owl as tool for understanding their environment. The focus was on identifying problems the Owl could help solve, the type of information it could provide, and how it could convey this information in a direct, embodied manner. During the sessions, I attempted to play an active role in enhancing participants' environmental awareness. By pointing out elements in the scene, I drew attention to areas of potential interest and demonstrated possible navigation routes using pull-signals, effectively guiding them towards their intended destinations.

Despite these efforts, it is observed that the type of information often needed for these explanations was spatial in nature, which posed a challenge for the embodied 'language' approach we were exploring. Participants expressed curiosity about their environment with questions like, "What can I do here?" or "What does my environment look like?" In these instances, the embodied explanations were insufficient to provide a comprehensive understanding of the surroundings.

A notable success, however, was the use of directional pulls towards a specified goal. This directional pull proved an intuitive way for participants to understand their relative location and orientation in relation to their destination and showed similarities to the pull of a guide dog. Nevertheless, for conveying detailed spatial or semantic information crucial for a deeper understanding of the environment, the tactile map emerged as a more suitable tool.

1.2 'PULLING' THE USER INTO EXPLORATIVE DIRECTIONS

- The Owl suggests possible routes, allowing the user to choose their path by indicating a direction.
- The system can provide subtle resistance (a light pull back) to indicate a denial or rejection of a chosen path.
- Owl suggests taking routes by slightly applying force in the direction of paths to stimulate exploration

In another direction for the interaction, while walking a regular route, the Owl would 'nudge' the user to take different routes by applying slight directional force. Two different scenarios were explored:

1. While passing an interesting route for exploration, the Owl applied slight force in this direction. The user could follow along by 'accepting' the Owl's pull and taking the suggested road. By pulling back, the participant 'denies' the pull of the device. A 'conversation'
2. At crossings of multiple roads, the Owl

could 'show' different potential roads by applying slight force in different directions at a time. the user would then pull/move in the desired direction to follow along with one of the routes.

In some situations this resulted in an interesting exploration and a fun new experience for the participant. The directional pull signal made participants aware of potential routes in their relatively familiar environment that they hadn't noticed before. This embodied signal indicated a possible path but didn't offer additional information about the destination of that route. Participants found it intriguing to think about where these new routes might lead.

However, a key issue emerged: participants did not want to take deliberate detours. This highlights a fundamental challenge in encouraging exploration among visually impaired persons (VIPs). VIPs typically prefer the easiest and most familiar route to their destination, as navigating unknown areas can be challenging and increases the risk of getting lost. Additionally, because of a lack of distant perception there curiosity is not triggered while perceiving these routes, so they have little incentive to explore the enviornment.

In this experiment, participants were aware they were being guided by a sighted person, which likely reduced feelings of insecurity or fear about finding their way. This might account for some participants' willingness to explore unfamiliar environments. However, this setup was not fully representative of real-world conditions where VIPs navigate independently. This implementation of the Owl might again require the addition of the dynamic tactile map, which would make the navigation of a known areas easier, less stressful and more interesing through increased environmental perception and might trigger curiosity due to increased distance cues.

CONCLUSION

The Owl for environmental perception and engagement needs to wait for the DTM

Helping the user perceive, experience and explore the environment is strongly dependent on the conveyment of spatial information and thus requires the DTM and the resulting environmental perception and capability/ confidence as a spatial actor. For this reason, it is decided that the direction of the Owl helping the user explore the enviornment is placed on hold until a functional version of the DTM is available for integrated experimentation with the Owl.

2 THE PARTNER WHO KEEPS AN EYE OUT

In this role, the OWI acted to reduce the user's need for constant vigilance. This was achieved through a different interactions. First, an approach to direct the user's hand towards potential obstacles or dangers revealed a need for more contextual information about the obstacles, as users often inquired about the nature of the hazard they were alerted to. This was particularly noticeable in well-known environments where users already had a mental map of typical obstacles. The challenge was to balance the provision of useful alerts without overwhelming the user with unnecessary information, especially in areas with multiple obstacles in close proximity.

2.1 THE OWI MAKES THE USER AWARE OF BY POINTING THE USER'S HAND TOWARDS OBSTACLES/DANGERS

The Owl acted as a collaborative partner, alerting users to obstacles or dangers by directing their hand towards them. However, users often wanted more information about the nature of these obstacles.

Obstacles/dangers are often difficult to perceive up front and can form a problem when they appear in your line of walking. in a known environment, these scene elements are often well known, because this type of information is one of the most important in the mental map. I therefore explored this interaction both in well-known and more unknown roads.

However, participants wanted to know the source of the warning: Pointing at scene elements caused the user to wonder what it is that they were made aware of.

While walking on a regular curb situation often affairs where many different obstacles were encountered close to each other. it became evident that highlighting all these different scene elements in this embodied fashion is very inefficient and leads to information overload

2.2 PUSH AND PULL LANGUAGE

The most interesting interaction explored is that of the embodied 'push-pull' language. This language allowed the Owl to communicate with users by applying forces in different directions and intensities. For instance:

The Owl would push the user away from imminent dangers. Different types of pushes and their intensities were explored to communicate the level of hazard. It was observed that users naturally became curious about the nature of these hazards, often testing the Owl's reactions to understand the severity of the danger.

For example, when moving towards a turn in the road that ended in a bush, P1 wanted to know what it was that they were certain suddenly pushed the way from. He tried to push through resulting in a stringent, almost panicked reaction/ push by the object, signalling that it was in fact not possible to move in this direction.

In contrast, while walking through town and experiencing a push away from a heightened curb that he is approaching, He decides to test this Hazard and experiences a significantly less stringent reaction. this tells him that it is safe to further explore in this Direction and he cautiously detects and steps onto the curb.

Of course, this behavior is not advisable due to its potential danger, but it must be acknowledged that the presence of a sighted guide during these tests likely influenced participants' willingness to engage in such exploration. The guide's presence provided a safety net, ensuring that participants would not be exposed to real danger. This effect however highlights the potential of the embodied push language used by the Owl. It demonstrates how such an interaction can facilitate a rich and meaningful collaboration between the user and the device.

NEGOTIATION THROUGH THE PUSH-PULL LANGUAGE

In the experimentation, ibecomes clear that a user needs to move in a direction that might pose dangers relatively often, which would result in the Owl counter-working the user's route: this is a clear misalignment of intention. To align the intentions of the user and the Owl, participants could 'push back' against the Owl's guidance to negotiate and indicate their intent to proceed in a certain direction such as crossing the road or stepping onto a heightened curb, despite potential risks. This interaction formed an interesting dynamic where the Owl and user could communicate and adjust their actions accordingly.

COLLABORATIVE TEMPO REGULATION

Apart from the push away from dangers, the push-pull can be used to control tempo and alertness in movement:

The Owl would hold back when the situation narrows and more alertness is needed, upon detection of upcoming environmental elements that require cautious, such as obstacles or a narrow pathway, and speed up when the path is clear or pull towards free/safe space. For a VIP without proper prospect into the path ahead, it is difficult to know which state is required. Er is dus een link tussen alertheid en tempo, en dit concept is interesting voor de exploratie:

This tempo change was found to be intuitive for participants, and showed similarities with their experiences with guide dogs in similar situations: P1:

"Je weet dan: Oh, er is wat, dus je loopt er dan niet zo lomp tegenop." and "Kijk, als je op een langer stuk komt en er is niks, dan ga je zelf ook harder want he, dat is lekker, lekker doorlopen"

CURIOSITY FROM THE COLLABORATION

The interaction with the Owl often sparked curiosity among participants, especially when encountering unexpected hazards. This curiosity underlined the importance of providing context to the alerts.

The collaboration as a virtual guideline

Another interesting (sporadically) observed reaction/strategy is how one participant made this push their own and used it for movement through a path, as a virtual guideline:

This participant carefully used the push to steer their movement: while walking on the curb the experience a sidewards force that pushes them away from an approaching obstacle. by following the direction of this Force They could navigate around approaching obstacles in a very natural manner.

This strategy required me to adjust the pushing Direction to be prospective and not just a way from obstacles: instead of pushing them backwards when an obstacle approached from their front right, I would push them mainly sidewards to account for their direction of movement.

CONCLUSION

The embodied push-pull language has a natural and direct mapping for movement, based on the principle that physical forces can effectively convey navigational intentions.

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.

Pushing Back to Signal Disagreement: When a user pushes back against the Owl's force, it signals their differing intention or desire to proceed despite the warning. The Owl can then recalibrate its response based on the user's feedback, potentially relaxing its force to accommodate the user's decision.

Due to its embodied nature, this push-pull language leverages the instinctive human response to physical forces and associations to interaction with a guide dog, and in doing so, it creates a direct and easily understandable method of communication between the device and the user.

Due to its embodied/direct nature and its interesting attribution of meaning, this interaction is considered as a useful extension for the environmental perception. This model interaction is chosen as the direction for the Object with Intent.

FUTURE RESEARCH

The current design direction of the OWI represents just one of many potential directions. The concept of an Owl is a relevant topic that requires further research. Three key areas for future exploration include:

1. **Integration of the Dynamic Tactile Map**

   A crucial improvement for future research is integrating the DTM with the Owl. The DTM enhances spatial perception, which in turn can boost confidence and reduce the need for constant vigilance. These improvements are essential for enabling an explorative mindset in users, a mindset that the Owl can effectively stimulate. Understanding how the DTM and Owl can work together to stimulate exploration and engagement with one's environment will be a significant focus, as it could greatly enhance the navigation experience for visually impaired users.

2. **Exploring Additional Roles for the Owl**

   For example:

   a. The Owl as a Teacher: One potential role is the educative partner that wants to show users how to effectively use the DTM through a collaborative exploration of environments.

   b. The Curious Explorative Partner: Another intriguing role is that of an explorative partner, which aligns with the Owl's need to 'see' or map the entire environment. This dual-purpose role not only aids in complete environmental mapping but also adds an element of discovery and adventure to the user experience.

3. **Refining the push-pull language**

   Finally, this push-pull language can be better explored as a means to provide extra environmental awareness. This will require more focused and extensive experimentation with this interaction.

APPENDIX J LIST OF REQUIREMENTS

The development of of the dtm requires attention to a wide range of factors - from technological innovation to functional efficacy, and from user experience to ethical considerations. The following comprehensive list of requirements is informs the design of the dynamic tactile map (dtm) concept.

VISION

1. Holistic R&D: Mobility for VIPs is multifaceted, involving physical, cognitive, and psychosocial dimensions. Assistive technologies need to address these varied aspects, focusing on more than just physical navigation.
2.

TECHNOLOGY

3. Utilize mainstream technology: integrate with existing technologies to minimize overlap and ensure user familiarity.

The concept must incorporate the following technologies:

4. Sensory technologies: incorporation of advanced sensory technologies to map environments in real-time and determine the user's orientation within the environment, such depth cameras, lidar, and imus
5. Interface technology: advanced haptic multidimensional interface to enable dynamic, spatial environmental perception and user interaction with the device
6. Owi embodied feedback technology: (inertial) force feedback technology that allows the device to 'push' and 'pull' the user to enable the imagined collaboration

ERGONOMICS REQUIREMENTS

7. Ensure portability: design the device to be lightweight, compact, and non-obstructive.
8. Ensure durability and reliability: use robust materials and guarantee performance under various conditions.
9. Optimize battery life and power management: provide long battery life and incorporate efficient recharging options.
10. Maximize comfort: ensure comfort during extended use.

TRUST AND INTERACTION

11. Embodied push-pull language: implement an embodied push-pull language for intuitive and direct communication between the device and the user. This should enhance perception and exploration of the environment.
12. Calibrated trust: ensure a transparent decision-making process in the owi to build trust and understanding between the user and the device. This includes trust-calibration mechanisms that were not considered in the initial research.

EMOTIONAL BENEFITS OF USE

13. Minimize mental strain: Provide comprehensive environmental overview to reduce vigilance and fear, and navigation-related stress and anxiety.
14. Foster environmental engagement: facilitate social interactions and encourage exploration.
15. Improve overall quality of life: enhance independence and promote a more active lifestyle. Enhance environmental interaction and exploration capabilities.

PERCEPTION WITH THE DTM

16. Reliable Distance Perception: Create a DTM that offers accurate spatial overview and orientation.
17. Easy overview: The solution must aid in creating and recalling mental maps with less cognitive strain.
18. Free movement: VIPs' movement is restricted in open spaces due to reliance on tangible guidelines. The solution should provide guidance in open spaces, allowing for freer movement.
19. Facilitate accurate distance perception: enable users to discern distances and hazards effectively.
20. Provide dynamic spatial awareness: update spatial information in real-time to adapt to changing environments.
21. Enhance environmental perception: combine sensors and ai for effective environmental data interpretation.
22. Support effective mental mapping: assist in mental map formation and recall for easier environmental understanding.
23. Incorporate multi-modal feedback: use auditory, tactile, and possibly olfactory cues.
24. Consider different scales of environment representation in the DTM.

STRATEGIC REQUIREMENTS

25. Focus on accessibility and affordability: make the technology widely accessible and cost-effective.
26. Ensure regulatory compliance: meet standards and certifications for assistive devices, for example with respect to the signalling function.
27. Target market identification: expand to larger market segments (i.e. with moderate visual impairments).
28. Pricing strategy: develop a pricing model that balances affordability for the end-users and the cost of advanced technology development. Consider insurance coverage and subsidies in pricing strategies.
29. Distribution channels: explore direct consumer sales alongside traditional channels like healthcare providers and specialty stores for assistive devices.
30. Low effort requirement as a selling point: leverage the ability of the dtm to accommodate different levels of visual impairment and user preferences as a key selling feature.

PLATFORM

31. Building a user community: foster a community for users to share experiences and suggestions for enhancements. This not only aids in product development but also builds a loyal user base.
32. Marketing strategy: develop a marketing strategy that emphasizes the technology's unique features, user benefits, and testimonials from early adopters. Highlight the technology's impact on quality of life, independence, and social engagement for vips.
33. Funding and financial planning: identify potential funding sources, including venture capital, government grants, and partnerships with non-profits focused on visual impairments, to support research and development, production, and marketing.
34. Adaptation to global markets: consider the cultural and regulatory differences in global markets for international expansion. Adaptation may include language, user interface design, and compliance with local laws and standards.
35. Training and support services: develop comprehensive training materials and support services for users and caregivers to ensure a steep learning curve and positive experience.

ETHICAL

36. Privacy and data security: develop a robust data security protocol to protect user information, which is crucial for user trust and legal compliance.

APPENDIX K FUTURE CONCEPT DESIGN

INTERFACE TECHNOLOGY RESEARCH

This research examines various haptic interface technologies to identify suitable options for creating a dynamic tactile map for the visually impaired. It compares technologies ranging from existing commercial products to those in the research phase, evaluating their capabilities, advantages, limitations, and future potential. The evaluation of haptic interface technologies focuses on key criteria that determine their suitability for dynamic tactile maps. These criteria are designed to ensure that the selected technology provides an intuitive, clear, and effective interface for visually impaired mobility. They include aspects such as non-blocking interaction, natural interpretability, environment display, precision, user experience, physical and technical feasibility, cost-effectiveness, and potential for future advancements. Each technology is assessed against these benchmarks to ascertain its overall efficacy.

1 CRITERIA FOR EVALUATION

Various haptic interface technologies are evaluated based on a set of criteria. The criteria include:

1. Non-blocking: allowing the user to interact with the environment during use.
2. The ability to depict environments with naturally interpretable directions
3. Comprehensive and meaningful environment display, clear distinction between different (types of) elements
4. Clarity and the ability to perceive of edges, transitions, and shapes
5. Clearly and precisely feel Movement underneath fingers, high refresh rate
6. Precision and Scale: The technology must provide accurate perception at a small scale while being able to display a larger environment.
7. Quick, easy & intuitive reading of the map
8. Physical and Technical Aspects: This includes the size and bulkiness of the device, durability,power consumption,
9. The ability to track finger or hand movements accurately.
10. Cost and Accessibility: Evaluating the commercial viability of the technology, including the cost of production, maintenance, and user accessibility.
11. Future Potential and Scalability: Considering the potential for future development and improvements, scalability, and adaptability to different environments and use cases.

2 PHYSICAL SCREENS

2.1 DIGITAL BRAILLE SCREEN

DESCRIPTION

Utilizes physical ‘taxels’ or braille cells that move up and down electronically to form a grid of points, translating text and simple graphics into a tactile format.

Status: Available on market

PRO’S/CONS

- + Clear transitions
- + Provides clear tactile feedback for text.
- + Direct and intuitive for Braille readers.
- - Limited to binary display, offering low resolution for complex images or maps.
- - Slow refresh rate, not ideal for dynamic content.
- - Bulky and fragile, challenging portability and durability.
- - Lack of multi-touch interaction limits the complexity of information that can be conveyed.
- - High cost, potentially limiting widespread adoption.

The Digital Braille Screen, while effective for textual information, faces challenges in dynamically representing spatial environments. Its adaptability to more complex and changing data like maps is limited, making it less suitable for dynamic tactile map applications.

2.2 ELECTROVIBRATIONAL DISPLAYS

Creates haptic sensations using oscillating electrostatic forces that attract the user’s finger-pad to the screen, simulating different textures.

Status: Research phase at Haptics Lab

PRO’S/CONS

- + High refresh rate, suitable for dynamic content.
- + Capable of displaying a variety of textures, enhancing environmental perception.
- + High resolution, limited only by the precision of finger location tracking.
- - Complexity in developing a universally understandable texture language.
- - Currently limited to single-finger interaction; multi-finger interaction reduces the quality of sensation.
- - The entire device may experience vibrations, potentially reducing user comfort.
- - The technology is still in the research phase, indicating potential limitations in immediate practical applications.

RESEARCHER’S NOTE:

“Ideally, one day, a user should be able to receive 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.” (Vardar et al. 2021)

Electrovibrational Display (Zhang 2015)

3 VIRTUAL (BODY-WORN) DISPLAYS

these screens are no physical screens but worn on the body, simulating physical screen in mid-air or on surface

2.1 ELECTRONIC SKIN

DESCRIPTION

A wearable technology embedded with sensors and actuators, designed to provide tactile feedback across the surface of the skin.

PROS/CONS

+ Minimally intrusive design, potentially enhancing user comfort.
+ Provides accurate feedback over the fingertip plane due to numerous actuators.
- Balancing accuracy of feedback with user comfort and device durability is challenging.
- Still in developmental stages, with practical applications yet unrealized.

Electronic skin presents a promising avenue for tactile feedback. Its effectiveness hinges on the balance between providing accurate feedback and ensuring user comfort and device durability.

3.2 SENSEGLOVE

DESCRIPTION

A glove that delivers force-feedback to simulate the sensation of touching virtual objects, with tracking of hand and finger poses.

PRO'S/CONS

+ Allows users to feel the shape of virtual objects.
- Limited to force-feedback; does not provide texture feedback.
- Bulky design due to sensors at all joints, which may hinder natural movement and long-term wearability.
- Only capable of displaying shapes at the finger-tips

While Senseglove excels in delivering force-feedback, its application in dynamic tactile maps may be limited due to the lack of detailed texture representation. The device's wearability and comfort for extended use are also critical aspects to consider.

Senseglove (2023)

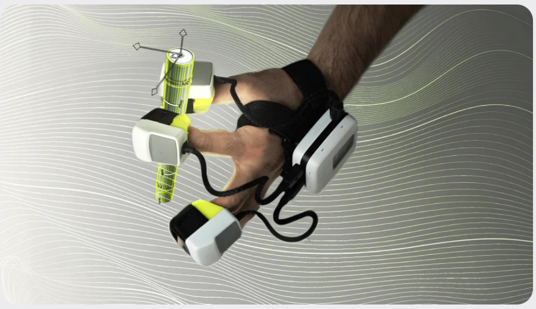
3.3 WEART HAPTIC FEEDBACK WEARABLE

DESCRIPTION

Combines force-feedback on fingertips, texture simulation, and temperature feedback, designed primarily for augmented reality and robotics control.

PRO'S & CONS

+ Multimodal feedback (force, texture, temperature) offers a rich user experience.
+ Accurate finger tracking enhances the realism of interactions.
+ Bulky technology
+ Only capable of displaying shapes at the finger-tips



Weart(2023)

3.4 REFERRED SENSATIONS: ELECTRODES OUTSIDE THE PALM TO SIMULATE SENSATIONS

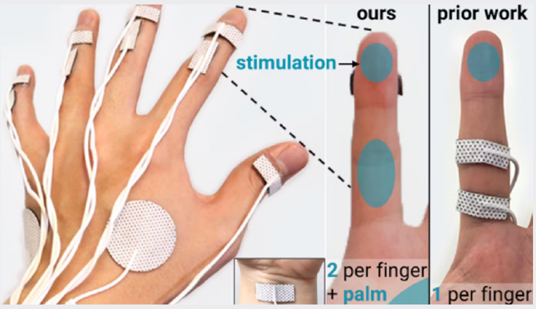
DESCRIPTION

A system provided by Tanaka, 2023, applies electrodes on the outside of the hand simulate sensation inside the hand by targeting the nerves inside the fingers. ("By strategically placing electrodes, building on a neurological concept called referred sensations"). The resulting electrode arrangement renders tactile sensations in 11 distinct locations on the palmar side of the hand (please refer to [14] regarding our evaluation). The fingers are tracked through camera feed from VR goggles

Status: Ongoing research

PRO'S/CONS

- Allows for unobstructed interaction with real-world objects.
- Virtual representation of finger location enhances spatial awareness.
- Limited to 11 feedback points, which may not provide precise tactile information.
- Dependent on camera visibility for hand tracking, which could be obstructed in certain environments.



Tanaka (2023)

3.5 FINGERNAIL HAPTICS

DESCRIPTION

PROS/CONS

- Actuates the whole finger at once, lacking granularity in feedback.
- Difficulty in perceiving detailed changes along the finger.

3.6 WEARABLE SPARSE ARRAY OF ACTUATORS FOR FOCUSED VIBROTACTILE STIMULI

DESCRIPTION

Array of actuators that can create ‘virtual actuators’ in any location in between through the ‘funneling’ effect.

Status: Early phase research in 2023

PRO’S/CONS

+ Allows for creation of virtual tactile sensations in different locations.
- Sensations can be difficult to localize, potentially confusing users.
- Requires wearing an explicit item on the body, which might affect user comfort and acceptance.

3.7 (WEARABLE RING) TO SIMULATE TEXTURES

DESCRIPTION

Wearable (finger worn) haptic displays that displays “virtual textures rendered via vibrations relocated to the base of the index finger” (Vadar, 2023)

Status: Research at Haptics Lab

PRO’S/CONS

+ Non-blocking and wearable, keeping hands and fingertips free.
+ Capable of displaying different textures for enhanced perception.
+ Display different textures for more meaningful perception
- Difficulty in perceiving clear edges and shapes due to the whole finger receiving the signal.
- The sensation of change is noticeable, but the lack of clarity in shapes may limit its effectiveness for detailed maps.

3 COMPARATIVE ANALYSIS

The comparison of haptic technologies reveals varied strengths and limitations in the context of dynamic tactile maps:

- Physical vs. Wearable Technologies: Physical screens like Digital Braille and Electrovibrational displays offer direct, tangible interaction but are limited by resolution and single-point interaction. Wearable technologies, such as vibrating rings and Senseglove, provide more freedom of movement but lack precision in conveying detailed map information.
- Texture Representation: Technologies like Electrovibrational displays and Weart Haptic Feedback Wearable show potential in texture representation. However, the complexity in creating a ‘texture language’ that effectively represents real-world elements remains a challenge.

4 CONCLUSIONS

The selection of the most suitable technology is influenced by a combination of factors including, user experience, technological maturity, and practical feasibility. The Electrostatic display and Haptic Augmented Reality system through electronic skin emerge as the leading candidates. However, given the nascent stage of Haptic Augmented Reality technologies, the electrostatic display is chosen as the preliminary step towards realizing a dynamic tactile map.

APPENDIX L
PROJECT BRIEF

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Electronic Tactile Map with Intent: project title

Please state the title of your graduation project (above) and the start date and end date (below). Keep the title compact and simple. Do not use abbreviations. The remainder of this document allows you to define and clarify your graduation project.

start date 06 - 12 - 2022 15 - 08 - 2023 end date

INTRODUCTION **

Please describe, the context of your project, and address the main stakeholders (interests) within this context in a concise yet complete manner. Who are involved, what do they value and how do they currently operate within the given context? What are the main opportunities and limitations you are currently aware of (cultural- and social norms, resources (time, money,...), technology, ...).

This project focuses on improving the independent mobility of visually impaired people (VIPs). It is a self-initiated project for a double master's degree in Integrated Product Design (IPD) and Design for Interaction (DFI) that builds upon a previous design project focused on enhancing mobility for individuals with visual impairments (VI), in collaboration with Bartimeus. The project is done in service of Koninklijke Visio, a large Dutch foundation with a long-standing commitment to empowering individuals with visual disabilities to lead independent and confident lives. For more than two centuries, they have been providing valuable information, advice, mentoring, revalidation, education, housing and research. Koninklijke Visio will be an integral part of the project team, lending their expertise, connection to the target group and providing the financial resources required to run the project. In return, they will receive ownership of the intellectual property generated by the project. By collaborating with Koninklijke Visio, I seek to enhance their mission of empowering individuals with visual impairments and make a positive social impact. During the project, I will work closely together with the Industrial Design Engineering faculty's Expressive Intelligence Lab (EIL). One of the research topics in the EIL is the creation of "Objects with Intent" (OwI), intelligent electronic products that act as independent agents and assume a more proactive role to create an interaction that is experienced as a collaboration by the user. This research is particularly relevant for VIPs, who may have difficulty interacting with digital technologies due to the inability to use visual cues. Within the project, the EIL seeks to advance their knowledge of the design of OwIs and learn how to implement the software for such devices.

Research and design for the improvement of VIPs' independent mobility is a relevant topic and will continue to grow in importance in the near future. In the Netherlands alone, over 300,000 people suffer from visual impairments, and this number is expected to continue growing due to factors such an ageing population and diabetes (Oogfonds, 2022). One of the most significant challenges faced by VIPs in their daily lives is the inability to travel independently, which can lead to social isolation and affect their productivity, employment, leisure, and self-maintenance activities. (Marston & Golledge, 2003; Walker & Lindsay, 2006): Reduced mobility due to visual impairment leads to seclusion and the literal shrinking of the living world of the VIP.

Many different mobility aids are available to VIPs, the most common of which being the white cane and guide dog. These tools typically require extensive training and become an important part of the VIP's mobility strategy, however, they each have their own downsides. The white cane is easy to carry, low-tech and thus reliable, but it only provides access to information about environmental elements that are within arm's reach and does not help with spatial orientation and problem-solving. The guide dog ensures secure, fast travel but the VIP must be willing to adopt a dog. Furthermore, the dog can become distracted and while it has access to a great number of environmental cues to form a navigational strategy, these cues are not available to the VIP themselves, who in turn remains dependent on the dog and has no knowledge of the environment themselves. To increase VIPs' environmental awareness (while travelling), during the last half-century many companies have entered the market with new, advanced electronic tools such as white canes that can warn of near obstacles (such as the WeWalk smart cane) or AI-powered glasses that can speak aloud information about the environment to the VIP (such as the Orcam). However, adoption rates of these more modern tools are low and they have failed to replace the familiar stick and guide dog (Chanana et al. 2017).

References can be found in Appendix C

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introduction (continued): space for images

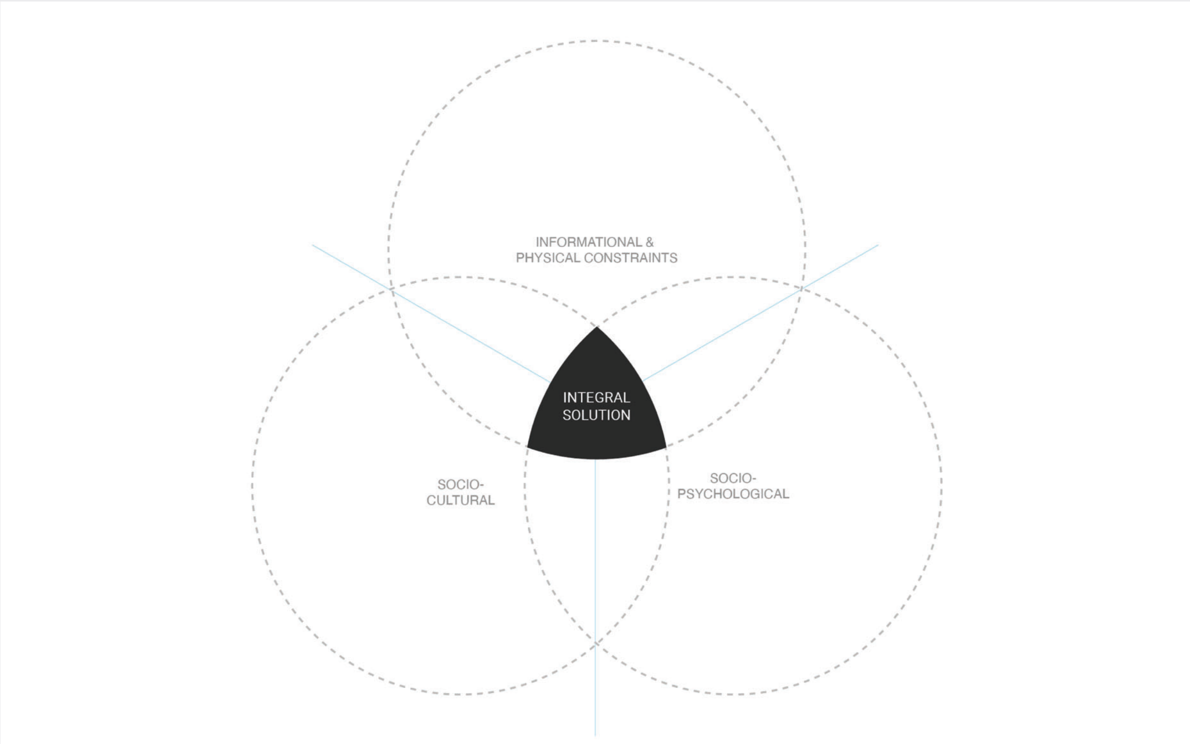


image / figure 1: The mobility problem is driven by much more than informational and physical constraints.

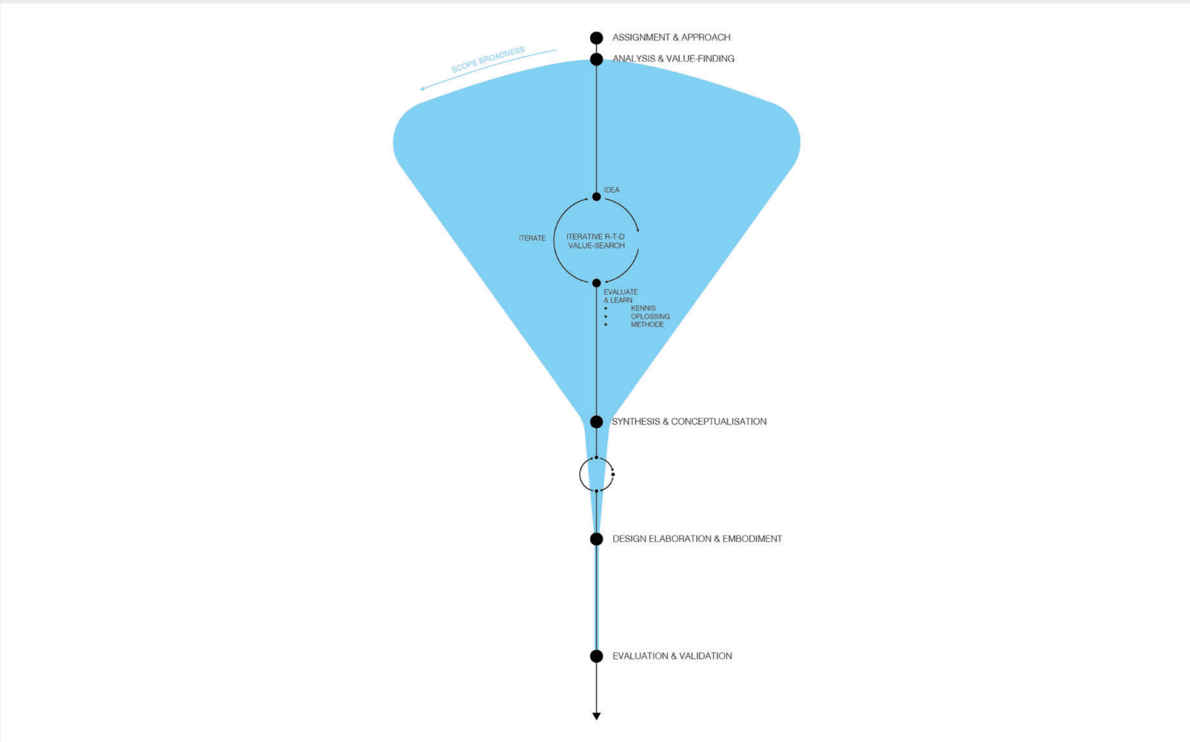


image / figure 2: the integrated design process and scope-development

PROBLEM DEFINITION **

Limit and define the scope and solution space of your project to one that is manageable within one Master Graduation Project of 30 EC (= 20 full time weeks or 100 working days) and clearly indicate what issue(s) should be addressed in this project.

The goal of the project is to design a new concept for an intelligent assistive device that improves independent VI pedestrian mobility. The focus lies on creating a valuable product that fits within the life of VIPs. Previous research by Mispelblom Beyer (2019) has shown that electronic tactile maps, refreshable tactile maps that provide detailed information about the user's immediate environment, showed on some form of haptic display, can effectively improve VI independent mobility, because of its ability to provide spatial information. This is important, because spatial orientation and problem-solving are the most essential prerequisites for VI mobility (Passini et al., 1986) that can be improved upon. Building on this finding, this project assumes an electronic tactile maps as the central technological concept. The core question driving this design project is: "How can I help VI users to independently and safely navigate new environments and make their way to their desired destination through the use of an electronic tactile map?"

Traditional research and the design of assistive technologies for VI often focuses mainly on the informational and physical constraints in VI mobility. However, mobility is a strongly (socio-)psychological and socio-cultural problem due to the inherent interaction of this individual with human or non-human others in the environment (Gleeson 1996, Middleton et al., 2019). The traditional view fails to take into account the complexity and human factors of the mobility problem. To design an effective and valuable solution to the mobility problem for VI individuals, an integrated approach is needed that takes a holistic view of human behavior and needs and, next to the informational and physical constraints, considers the socio-psychological and socio-cultural factors.

Concluding, I want to design the assistive device:
- based on an integrated approach to the VI mobility problem
- with a tactile map as the central technological concept
- to be an Object with Intent, an intelligent agent that takes on a more active approach in the interaction with the user to establish a partnership-like relationship

ASSIGNMENT **

State in 2 or 3 sentences what you are going to research, design, create and / or generate, that will solve (part of) the issue(s) pointed out in "problem definition". Then illustrate this assignment by indicating what kind of solution you expect and / or aim to deliver, for instance: a product, a product-service combination, a strategy illustrated through product or product-service combination ideas, ... In case of a Specialisation and/or Annotation, make sure the assignment reflects this/these.

Goal of the project is to create a new concept for an assistive device. It is not my objective to create a market-ready product within this project, as the focus of the project is on identifying new value, rather than on refining and preparing for production. I will advance the concept to (1) a functional prototype that is validated in a controlled environment (2) an experiential prototype that is validated in the actual context

As an initial definition of the assistive device that will be designed during this project is as follows:
In this project, I will design an Electronic Tactile Map with Intent, which will consist of the following components (at minimum) in order to fulfil its main function:
1. An interface that consists mainly of a haptic screen, which serves as the primary means by which the user accesses information from and interacts with the device. The most important function of the screen is communicating real-time information about their immediate environment in an effective and efficient manner, and thus relies strongly on the formation of a smart mental model for information representation.
2. A technology that gathers above-mentioned real-time information about the user's immediate environment, such as a 3D camera and/or other online technology.
3. A computing system to process and combine input data.
4. An Object with Intent (Owl) that overlays and augments the haptic map. Through the interface, the Owl communicates with the user and expresses its agency, the nature of which is to be defined during the value-finding phase of the project.
This initial definition of the assistive device to be designed serves as the foundation for the project. The specific design of the device and its components will be refined and developed throughout the course of the project.

Key objectives for a successful course of this design project are shown in Appendix A

Initials & Name J.Q. Mispelblom Beijer Student number 4351746

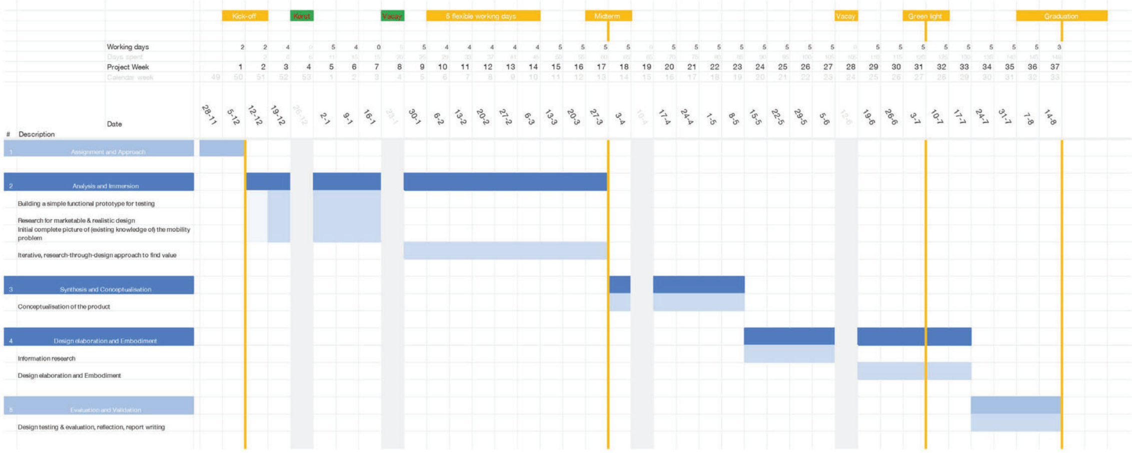
Title of Project Electronic Tactile Map with Intent:

PLANNING AND APPROACH **

Include a Gantt Chart (replace the example below - more examples can be found in Manual 2) that shows the different phases of your project, deliverables you have in mind, meetings, and how you plan to spend your time. Please note that all activities should fit within the given net time of 30 EC = 20 full time weeks or 100 working days, and your planning should include a kick-off meeting, mid-term meeting, green light meeting and graduation ceremony. Illustrate your Gantt Chart by, for instance, explaining your approach, and please indicate periods of part-time activities and/or periods of not spending time on your graduation project, if any, for instance because of holidays or parallel activities.

start date 6 - 12 - 2022

15 - 8 - 2023 end date



The project spans a period of 150 days. I will work full-time on the project and introduce some vacations and flexible off-days, based on personal ambitions point #4.

Approach
As stated, a holistic and complete overview of the complexity of the mobility problem is key. Therefore, the value-finding phase at the start of the project is extensive. This phase will start with a wide scope and mapping of the problem space to find important human factors for the design of the device. Then, I will assume an iterative research-through-design approach to find value for the assistive device and form one or more design concepts. During this phase, the understanding of the problem space will grow further.
It is my personal interest and that of the Expressive Intelligence Lab to see how such an Owl could be implemented in software and hardware. Therefore, in the end of the project, some extra time is reserved for the finalisation of the functional/experiential prototype. A further elaboration on the project plan is shown in Appendix B

MOTIVATION AND PERSONAL AMBITIONS

Explain why you set up this project, what competences you want to prove and learn. For example: acquired competences from your MSc programme, the elective semester, extra-curricular activities (etc.) and point out the competences you have yet developed. Optionally, describe which personal learning ambitions you explicitly want to address in this project, on top of the learning objectives of the Graduation Project, such as: in depth knowledge a on specific subject, broadening your competences or experimenting with a specific tool and/or methodology, ... Stick to no more than five ambitions.

My passion for this project stems from my desire to master the art of designing meaningful high-tech products through an integrated, human-centred design process that lies at the symbiosis of both my master's degrees. Within the project, I identify the following personal ambitions:

1. Iterative, research-through-design centred finding of value
I want to train myself further by going consciously and curiously through the R-t-D process, with an emphasis on deepening my understanding of the mobility problem and all related aspects, gaining knowledge about potential solutions, refining my approach to the process itself,and ultimately synthesizing my findings into a cohesive concept direction.

2. Advanced prototyping & electronics skills
I plan to utilize a functional prototype of a live tactile map for testing, informed by the insight from previous work that static maps are not sufficiently representative for simulating dynamic maps.

2a. Learning ROS
To achieve this, I have identified the Robot Operating System (ROS) as a suitable platform for creating the prototype. ROS allows for the creation of a modular system comprising advanced components such as a 3D camera and haptic display, enabling the easy substitution of elements within the system. Furthermore, I see ROS as an interesting and logical next step in my learning process.

2b. teratively building and expanding the prototype
I plan to take an iterative approach to the construction and expansion of the prototype. Rather than attempting to implement the entire system at once, I will begin with a simple version, comprising a minimal set of assumptions. This initial prototype will serve as the basis for subsequent iterations, which will be informed by the results of testing and validation. This will help ensure that the design does not become overly complicated and that underlying assumptions of the various elements of the design are validated individually, before being incorporated into the prototype.

3. Creative facilitation & participative research
I am eager to gain experience in creative facilitation and conducting generative sessions aimed at (1) finding user value and (2) stakeholder management. By gaining experience in these areas, I will be better equipped to manage an integrated design process on my own.

4. Balance work & life
I believe a full immersion in a design project is essential for achieving optimal results. I tend to feel emotionally connected to the target group and design problem, which introduces the risk of thinking about it constantly, also outside work-hours. It will be my personal goal to manage this well: I plan to maintain regular working hours of 9-17, and to schedule regular time off, including vacations and flexible free days, throughout the course of the project.

FINAL COMMENTS

In case your project brief needs final comments, please add any information you think is relevant.

Master's Thesis

January 2024

Graduate student

Juerd Mispelblom Beijer

Accomplished at

Delft University of Technology

Faculty of Industrial Design Engineering

MSc. Integrated Product Design

MSc. Design For Interaction

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