VAMO

A product-service system for independent visually impaired mobility

by Karlijn Borremans

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Disclaimer
This master thesis is written in context of the master Integrated Product Design at the faculty of Industrial Design Engineering at the Delft University of Technology in The Netherlands.

June 2025

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VAMO:

A product-service system for independent visually impaired mobility

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Preface

Dear reader,

In the following report, you are going to read my final delivery for my master thesis report. Here I described my story of designing for the world of people who are both visually and mobility impaired. The idea for this project started taking shape in the fall of 2024, when I knew I wanted to align my graduation project with my ambitions as a designer.

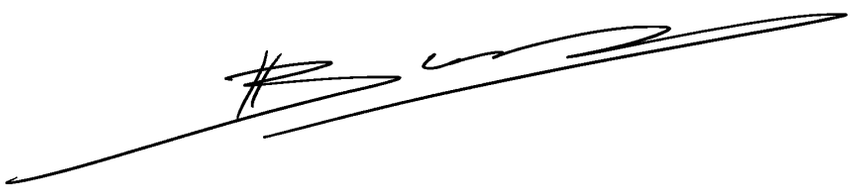
From the moment I began my studies in Delft, I wanted to do meaningful work, something that would allow me to apply my skills in a way that contributes to the world. What better way to give something back than doing what I love and what I'm good at?

Initially, I found a company whose mission aligned closely with my personal ambitions to work on a project with a positive impact. It felt like the perfect opportunity to contribute to a product that could improve the lives of thousands.
Unfortunately, due to contractual complications, we had to make the difficult decision to part ways right before the midterm presentation. While this was a stressful and uncertain time, it led me to develop a more independent, user-centred and flexible design, one that I believe is best for the envisioned user.

Throughout the entire project it remained a wonderful and interesting topic to design for. I felt a lot of enthusiasm, not only from me, but from everyone I told about my thesis. I am honestly very excited about my work and hope you are too.

I hope you will enjoy reading my thesis,

Karlijn Borremans



Delft, June 2025

Acknowledgements

I would like to thank a few people who have helped me throughout this intense and inspiring process.

First, I want to thank **Jan Willem** for his insightful questions and steady guidance throughout this project. Your thoughtful feedback and challenging perspectives pushed me to go further than I thought I could. Your encouragement and honesty led me through difficult moments and helped me grow in confidence.

I also want to thank **Vince**, it was wonderful to work with your creative and enthusiastic energy again. I know this was your first time coaching a graduation student, and I think you did a great job, your dedication and engagement made a real difference for me.

And **Robert**, I cannot thank you enough for all your help and support throughout my project. You were absolutely and unconditionally always available when needed, checking up with me, motivating me. Your contribution was immeasurable.

To **my family**, thank you for your endless support, for always being curious about my project, and for lifting me up with your insights, practical advice, and emotional encouragement.

A special thanks to my dear friend **Caro**, who selflessly made time to guide me, brainstorm with me, and support me like a third coach. Your help was invaluable.

To the company I initially collaborated with: despite the difficulties, your involvement helped shape the early direction of this project. I learned a lot from this experience and believe it contributed to my growth as a designer.

Tools and AI usage

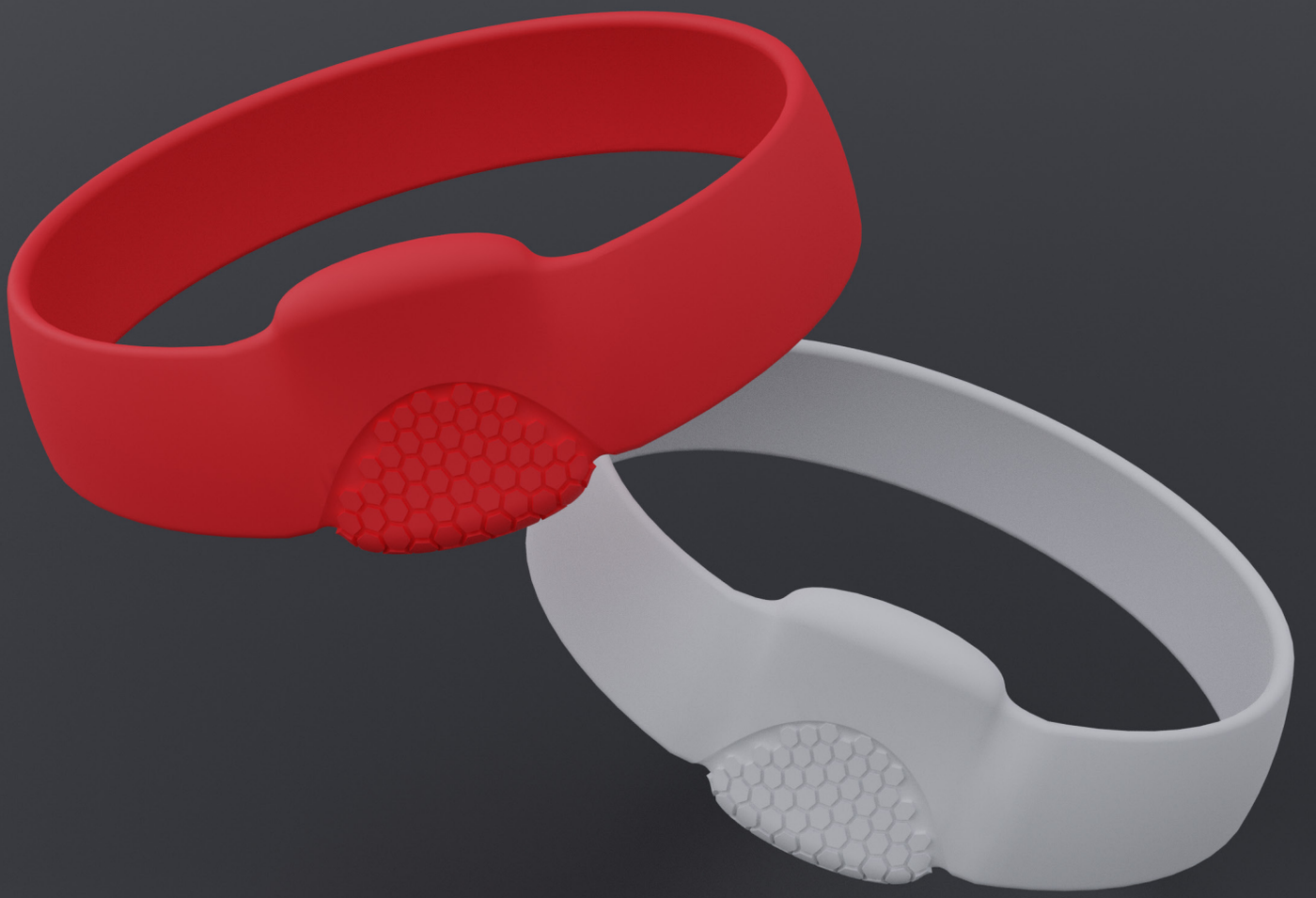
In the interest of transparency, I would like to mention the AI tools I used throughout this project to support ideation, writing, and prototyping:

ChatGPT (OpenAI) – for writing support, technical explanation, brainstorming ideas, and generating code in Python (e.g., for object detection prototyping).

Napkin – for creating quick visual sketches and diagrams.

DeepL – for accurate and natural translation between Dutch and English.

I used these tools thoughtfully and responsibly. Every design choice, analysis, and programming decision was made by me. ChatGPT was used to support and speed up the process, not to replace critical thinking. I used it not only for writing or generating code, but also to help me understand how the code works. When using AI-generated scripts, I made sure to review and adapt them carefully, often cross-referencing with documentation and trusted sources to verify accuracy and ensure that I understood what I was implementing. Any code was tested and iterated upon in the context. I ensured that no user data or sensitive content was shared, and I remained the sole author of all submitted work.



Abstract

This thesis explores the development of a product-service system that supports independent mobility for individuals with both visual and mobility impairments (MVIPs). These individuals face unique challenges, as existing mobility aids do not adequately address the combined limitations of impaired vision and restricted physical movement. The project aims to bridge this gap by integrating environmental sensing and tactile feedback technologies into a rollator-based system. The design approach follows a human-centered and iterative process, combining desktop research, stakeholder interviews, user testing, and prototyping.

The final outcome, VAMO, consists of modular components that can be mounted on an existing rollator and paired with a digital interface. The system provides users with real-time spatial awareness via vibration feedback, facilitating safer navigation. The project evaluates the effectiveness of the feedback system through user testing and expert reviews. While the solution is not universally applicable due to user diversity, it demonstrates the potential for inclusive design to improve quality of life and autonomy for MVIPs. The thesis contributes to the field of assistive technology by proposing a scalable and adaptable mobility aid that aligns with current trends in modularity, personalization, and accessibility.

Glossary

ADL: Activities of daily living

AI: Artificial intelligence

LLM: Large language model

LiDAR: Light detection and ranging

MIP: Mobility impaired person

MVIP: Mobility and visually impaired person

NLP: No light perception

Radar: Radio detection and ranging

Rollator vs walker: In this project the type of mobility aids, walkers on wheels, will be referred to as rollators, walkers without wheels, and thus with legs, will be referred to as walkers.

***Disclaimer:** This distinction is not defined and in other papers different definitions could've been used.

SLAM: Simultaneous localization and mapping

TDU: Tongue display unit

ToF: Time of flight

UI: User interface

UX: User experience

VIP: Visually impaired person

Index

0.1 PREFACE | 6
0.2 ACKNOWLEDGEMENTS | 8
0.3 TOOLS AND AI USAGE | 9
0.4 ABSTRACT | 11
0.5 GLOSSARY | 12

1.0 ASSIGNMENT AND APPROACH | 16
1.1 INTRODUCTION | 19
1.2 PROJECT PARTNERS | 20
1.3 DOMAIN AND SCOPE | 22
1.4 PROJECT APPROACH | 28

2.0 ANALYSIS AND IMMERSION | 30
2.1 TARGET GROUP | 34
2.2 MARKET AND DOMAIN ANALYSIS | 44
2.3 CURRENT SITUATION | 60
2.4 STAKEHOLDER PERSPECTIVES | 70
2.5 CONCLUSION | 78

3.0 SYNTHESIS AND CONCEPTUALIZATION | 80
3.1 CONCEPT DIRECTIONS | 85
3.2 FINAL CONCEPT DIRECTION | 87
3.3 CONCEPTUALIZATION | 89

4.0 ELABORATION AND EMBODIMENT | 90
4.1 ASSIGNMENT ELABORATION | 95
4.2 SYSTEM OVERVIEW | 96
4.3 DIGITAL EMBODIMENT |103
4.4 PHYSICAL EMBODIMENT |107
4.5 FINAL DESIGN |120

5.0 EVALUATION AND VALIDATION |126
5.1 PROTOTYPING |131
5.2 EXPERT EVALUATION |132
5.3 USER EVALUATION |133
5.4 CONCLUSION |136
5.5 FINAL DESIGN DISCUSSION |138
5.6 RECOMMENDATIONS |140
5.7 PERSONAL REFLECTION |142

6.0 REFERENCES |144

7.0 APPENDICES |154

CHAPTER 1

Assignment & approach

1.1 INTRODUCTION | 19

1.2 PROJECT PARTNERS | 20

1.3 DOMAIN AND SCOPE | 22

1.3.1 CONTEXT AND PROJECT BACKGROUND | 22

1.3.2 SCOPE | 24

1.3.3 PPRELIMINARY PROBLEM STATEMENT | 26

1.3.4 PRELIMINARY OBJECTIVE | 26

1.4 PROJECT APPROACH | 28

1.1 Introduction

Before the kick-off of this graduation project, preparatory work was done to ensure a smooth and efficient start. In this Assignment and Approach section of the report all the framework is provided for an intuitive, but intentional process. First and foremost, the project partners are presented and acknowledged. Necessary project background and context is laid out and the domain of this project is defined. The challenges and opportunities that come with this framework are set up and discussed throughout the report. Using a scope, a problem statement and several objectives the direction and intentionality of this project are emphasized. In the end, the assignment description is put forward, considering all the aforementioned preparation and the general approach for the project is explained.

1.2 Project partners

TU Delft

The Delft University of Technology, commonly known as the TU Delft, is the academic foundation for this graduation project. This graduation project marks the final phase of the master Integrated Product Design (IPD) at the faculty of Industrial Design Engineering (IDE), one of the eight faculties that the TU Delft is home to.

Role in the Project

The university provides access to facilities, academic resources, and expert supervision, ensuring that the project adheres to high academic standards. Faculty members offer guidance on research methodologies, design processes, and technical development, contributing to the project's overall success and relevance in the field of assistive technology. The project is guided by the TU Delft via two IDE staff members. In addition to guiding the project, the project supervisors will also assess this project on its quality.

1.3 Domain and scope

1.3.1 Context and project background

Context

Mobility is a fundamental aspect of independence, yet for mobility and visually impaired persons (MVIPs), navigating daily life is a grand challenge. Traditional rollators, support canes or wheelchairs offer stability and support for people with walking difficulties, while mobility aids like white canes, guide dogs or even artificial intelligence (AI) assisted apps can assist individuals with visual impairments.

However, there is currently a lack of solutions that effectively combine these functionalities, leaving a critical gap in assistive technology (see Figure 1). This project aims to bridge that gap by developing a solution specifically designed for MVIP's, ensuring a safer and more intuitive navigation.

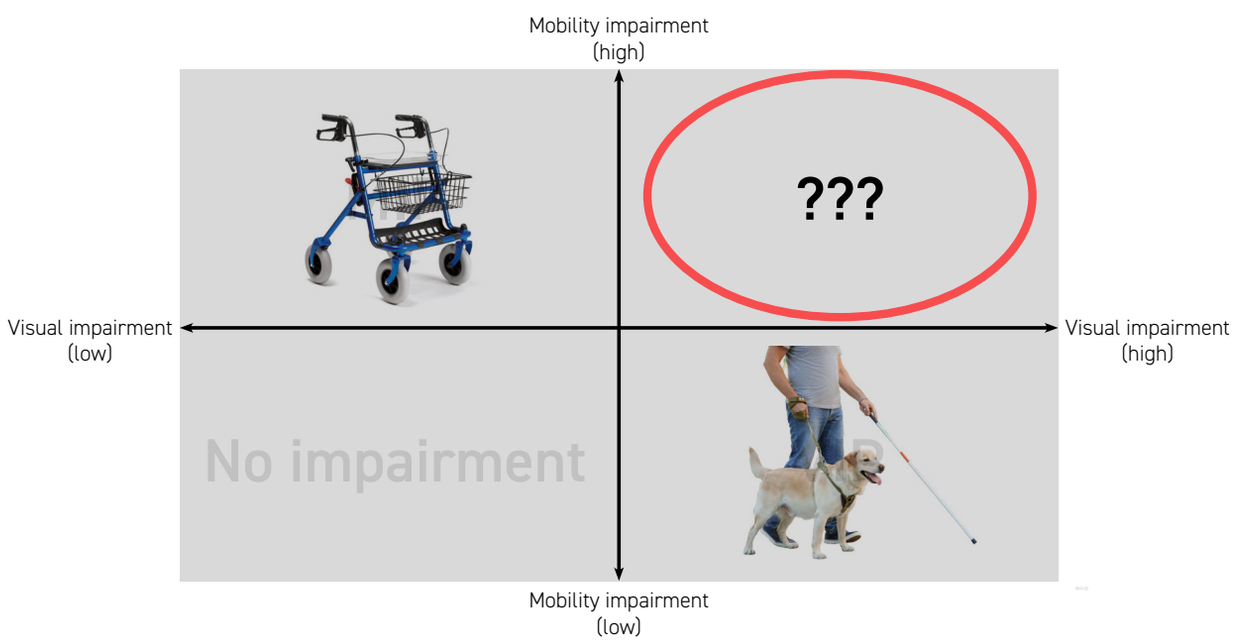


Figure 1: Assistive technology matrix

Domain

The domain of this project oversees assistive technology, human-centred design, and smart mobility solutions. With the rapid advancements of today in sensor technology, haptic feedback technology, AI and digital connectivity, mobility aids are becoming increasingly intelligent and adaptable. Many smart mobility devices focus on wheelchair users or independent navigation for visually impaired individuals, but few directly address the unique needs of MVIPs. By exploring how technologies such as obstacle detection, tactile feedback, and adaptive controls can be integrated into a rollator, this project seeks to enhance user autonomy and safety in various environments.

Additionally, this project is also approached from an inclusive design perspective. By looking at physical, cognitive and emotional barriers in the lives of MVIPs, the aim is to develop a solution that fully resonates with the user and is made for use in the 'real' world. Engaging with different stakeholders, like the user, physiotherapists, experts from knowledge institutions etc., will provide valuable insights into how current mobility aids fall short and what features would improve daily experiences.

Ultimately, this project contributes to the broader goal of creating more inclusive urban environments, in line with the European directive to make products and services more accessible for people with disabilities as well as the sustainable design goals (SDGs), where individuals with complex mobility needs can navigate public spaces with greater confidence and independence (Ministerie van Algemene Zaken, 2022) (Goal 10 | Department of Economic and Social Affairs, n.d.).

Opportunities and challenges

The integration of feedback technology into mobility aids presents both opportunities and challenges. Feedback has the potential to improve user experience by offering real-time, tactile guidance. However, ensuring intuitive and non-intrusive feedback, ergonomic comfort, and seamless integration with existing mobility aids poses technical and design challenges. Other challenges could be ensuring safety for this vulnerable target group.

In the analysis phase key points including opportunities and challenges will be summarized after each sub chapter starting from chapter 2 Analysis & immersion.

1.3.2 Scope

To make this thesis manageable, a scope for this project was devised, which is shown in Figure 2. This visual describes seven different aspects of the project. The different layers describe the level of importance of different subject matters within the aspects of the project. The centre of the circle indicates the most important subject matters and the most outer layer the least important. The red outer layer contains the things that will be excluded from this research. The goal of this visual is to provide a clear overview of the relevance of the matters, guide the project into the desired direction and protect it from addressing less relevant subjects and thereby losing valuable project time.

The most pressing scope boundaries are the target group consisting of people that have visual impairments as well as difficulty walking to the extent that they would need to use both visual support tools as well as walking aids, therefore creating a problem where they are not able to use both at the same time and hence are unable to walk independently. In this instance the term 'independent' is defined as without the help of another person. This project will focus on developing a solution that integrates with an existing walking aid, rather than designing a new one from scratch. While the outcome may be modular or adaptable for broader use, some testing during this thesis will be carried out using a specific, commercially available rollator . The scope is therefore limited to designing complementary parts for that rollator. It is also important to note that there will be an emphasis on the workings of the product, how technologies are integrated with each other will be explained but as they make use of widely accepted and used technologies, will be discussed less intensively.

Figure 2 : Scope visual

1.3.3 Preliminary problem statement

Mobility and visually impaired individuals, especially those who are completely blind, face a paradoxical problem when it comes to mobility aids: they cannot effectively use a visual aid like a white cane while also operating a walking aid like a rollator, yet they may be unable to walk safely without one. As a result,

'Mobility and visually impaired people struggle to find a mobility solution that provides both support and environmental awareness, limiting their independence, general health and safety.'

This project aims to bridge that gap (Figure 1) by enhancing the functionality of a walking aid with sensory feedback, allowing visually impaired users to receive real-time navigation and obstacle information without relying on additional visual aids. By integrating this technology, the walking aid becomes a more viable and attractive option, reducing the barriers to adoption and increasing mobility opportunities.

Users gain greater independence and safety, caregivers experience reduced concerns about safety and physiotherapists can recommend a more adaptive mobility aid. Addressing this issue within the given timeframe will focus on confirming proof of concept, guaranteeing increased safety, accurately conveying feedback and visualized concept form.

1.3.4 Preliminary objective

The preliminary objective of this thesis is to:

'Create a product service system for mobility aids to improve independent mobility and safety for visually impaired users in daily life.'

This goal is aimed at improving MVIPs quality of life. The objective is to reach this goal within the scope as visualized in Figure 2, hereby ensuring a focused approach that combines desirability, viability and feasibility.

1.4 Project approach

Assignment

The project will follow an adaption of the Double Diamond method (The Double Diamond, n.d.), with therein two Basic Design Cycle iterations (Roozenburg & Eekels, 1996). The first cycle will focus on research and defining design requirements and implications (discover and define), while the second will emphasize refinement, prototyping, and validation (develop and deliver). The overall structure of the approach is visualised in Figure 3.

First phase

In the first phase, desktop research, literature review, market analysis and stakeholder interviews to identify product requirements will be conducted. Additionally, existing walking aids will be analysed, and the customer journey will be mapped, synthesizing insights into design requirements. This phase will include a highly detailed analysis report and a look ahead for the second phase. At the midterm evaluation will be determined what the further, more detailed course of the project will entail.

Second phase

The second phase will be another design cycle, this starts with refining the starting values and possibly adding additional analysis material. This phase focuses on prototyping, testing and validation, ensuring the design meets usability, safety and feedback effectiveness goals.

There will be weekly meetings with the academic supervisors to ensure alignment.

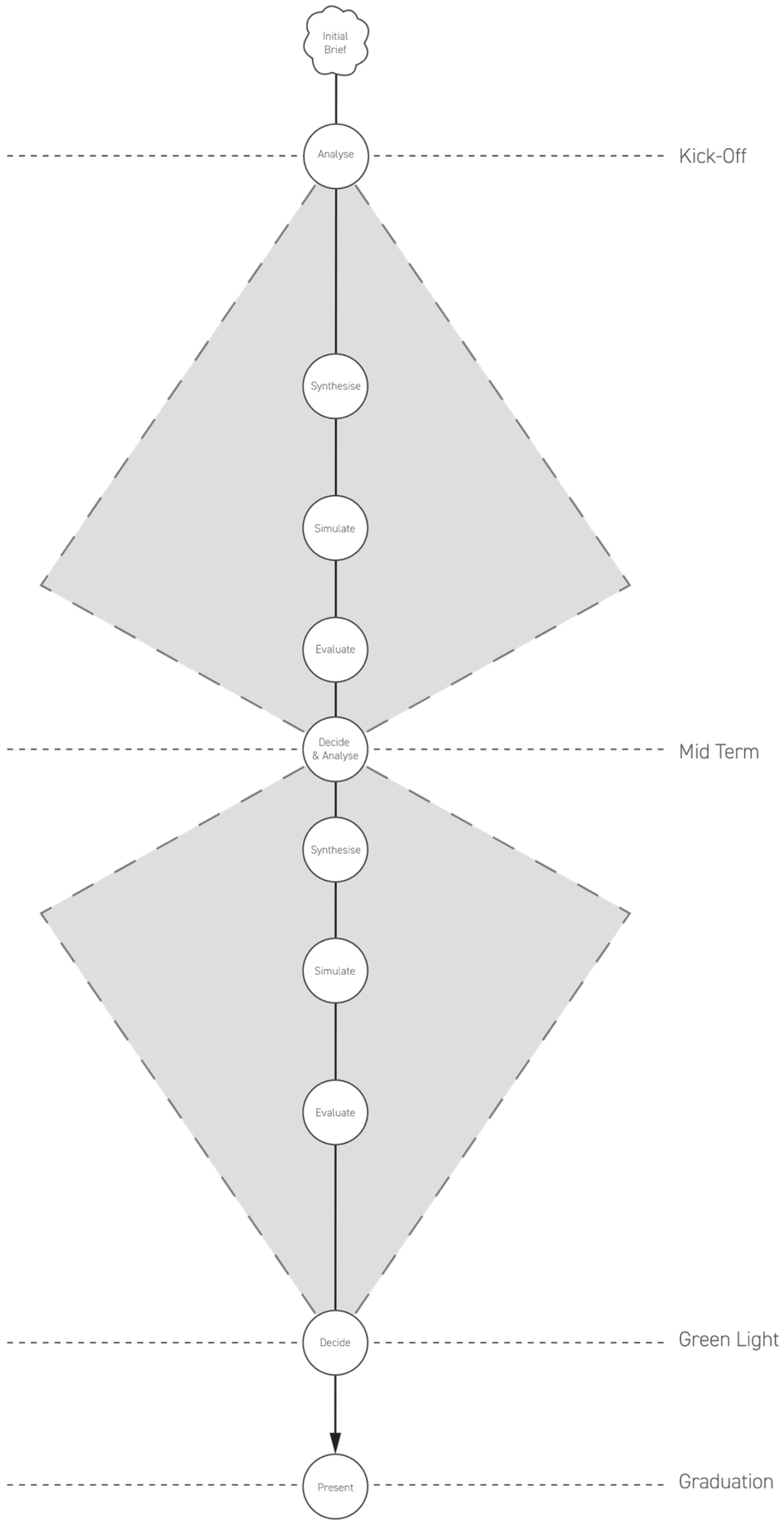


Figure 3: General Project Approach

CHAPTER 2

Analysis & immersion

2.1 TARGET GROUP | 34
2.1.1 BLINDNESS AND VISION IMPAIRMENT | 34
2.1.2 MOBILITY IMPAIRMENT | 38
2.1.3 WALKING AND VISUAL IMPAIRMENTS (MVIP) | 41
2.1.4 KEY POINTS: TARGET GROUP | 43

2.2 MARKET AND DOMAIN ANALYSIS | 44
2.2.1 RELATED WORK | 44
2.2.2 TECHNOLOGY | 46
2.2.3 TRENDS IN MOBILITY AID SECTOR | 53
2.2.4 SAFETY AND REGULATIONS | 56
2.2.5 KEY POINTS: MARKET AND DOMAIN | 58

2.3 CURRENT SITUATION | 60
2.3.1 CUSTOMER JOURNEY | 60
2.3.2 LIMITATIONS OF CURRENT MOBILITY TOOLS | 61
2.3.3 PHYSICAL OBSTACLES | 63
2.3.4 MENTAL BARRIERS | 65
2.3.5 KEY POINTS: CURRENT SITUATION | 68

2.4 STAKEHOLDER PERSPECTIVES | 70
2.4.1 THE MVIP PERSPECTIVE | 70
2.4.2 ‘KENNIS OVER ZIEN’ AUTHORITIES | 73
2.4.3 HEALTHCARE PROVIDERS | 74
2.4.4 GOVERNMENT | 75
2.4.5 DESIGNERS AND MANUFACURERS | 76
2.4.6 KEY POINTS: STAKEHOLDER PERSPECTIVES | 77

2.5 CONCLUSION ANALYSIS | 78

2.0 Analysis & immersion

This phase involves gaining a thorough understanding of the project issues at hand, by delving deeper into the world of MVIPs. The combination of literature review, market analysis and stakeholder conversations and interviews is discussed in this chapter. To ensure the readability of the following text a structure was made. The analysis begins with an examination of the target group, followed by a comprehensive market and domain analysis. Next, the current state of the MVIP world is visualised and examined. Finally, the various stakeholder perspectives are explored before the analysis concludes with key findings and next steps for the remainder of the project. In Figure 4 an overview of the subject matters is visualised.

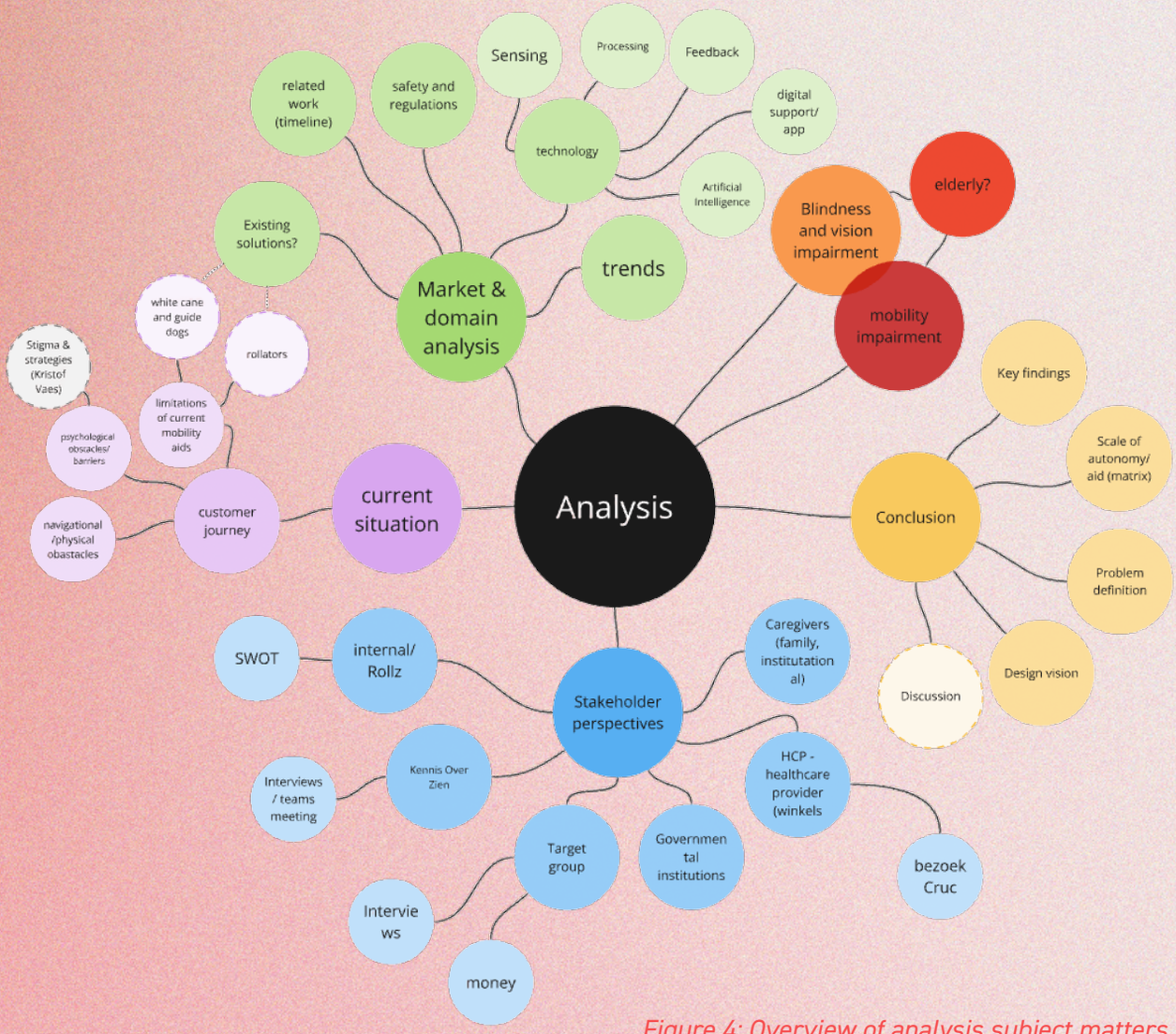


Figure 4: Overview of analysis subject matters

2.1 Target group

This section touches upon the prevalence, causes, and challenges associated with visual impairments and separately also with mobility impairments. It highlights the barriers MVIPs face in areas such as navigation, daily activities, employment, and independence. Additionally, it examines the unique difficulties encountered by those who experience both impairments simultaneously (MVIPs), emphasizing the need for specialized assistive technologies. These findinvgs were acquired from literature review as well as outcomes from conversations with stakeholders.

2.1.1 Blindness and vision impairments

Definitions

Blindness and visual impairment can be categorized based on two main criteria:

- **Functional:** Based on the degree of disability and its impact on daily life.
- **Medical**: Measured through visual acuity (VA) and visual field assessments.

The most widely accepted definition of blindness, often used for determining eligibility for disability benefits and pensions, describes it as having a central visual acuity of 6/60 (20/200) or worse, in the better eye with the best corrective lenses. Alternatively, a person may be classified as blind if their visual field is restricted to 20 degrees or less, severely limiting peripheral vision (see Figure 5) (WHO Expert Committee on Health Statistics & Organization, 1952).

A broader definition includes "economic blindness", which refers to vision loss that prevents individuals from performing essential work tasks, even if their condition does not meet strict medical criteria for blindness. This definition shows the socio-economic impact of severe visual impairments, emphasizing the need for accessibility and fitting support systems (WHO Expert Committee on Health Statistics & Organization, 1952).

Prevalence

Worldwide approximately 2.2 billion people had a form of visual impairment (including blindness) in 2019 (Fricke et al., 2018; World Health Organization, 2019). More than 250,000 people in the Netherlands have a serious visual impairment. That number is increasing rapidly, due to an aging population and the increase in the number of people with diabetes ('Visuele beperkingen', 2023).

Total blindness describes those who have a complete lack of light perception, officially described as no light perception (NLP). Only about 15% of people with eye disorders have total blindness, the majority of

Category	Visual acuity in the better eye	
	Worse than:	Equal to or better than:
Mild vision impairment	6/12	6/18
Moderate vision impairment	6/18	6/60
Severe vision impairment	6/60	3/60
Blindness	3/60	
Near vision impairment	N6 or M 0.8 at 40cm	

Figure 5: "Classification of severity of vision impairment based on visual acuity in the better eye" (World Health Organization, 2019)

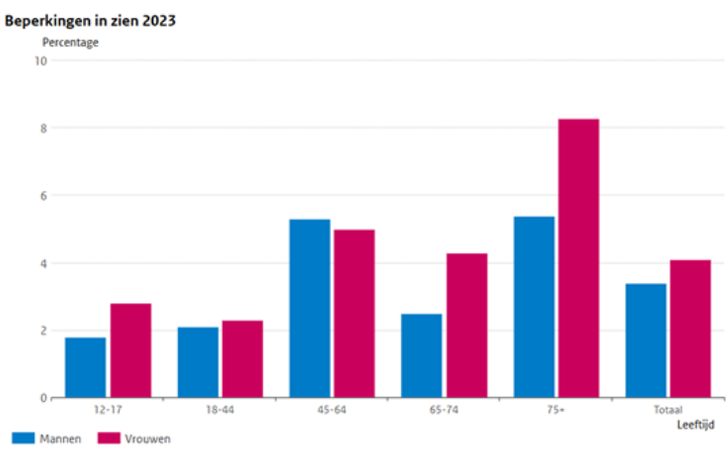
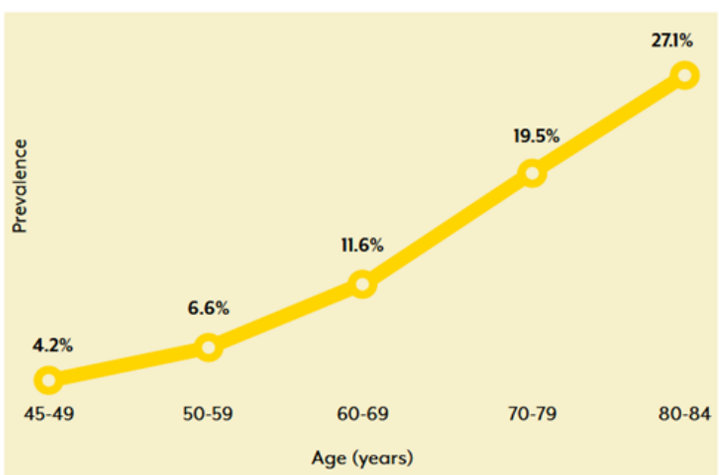


Figure 6: Disability in sight (Plasmans et al., 2024)



Adapted from: Wong WL, Su X, Li X, Cheung CM, Klein R, Cheng CY, et al. Global prevalence of age-related macular degeneration and disease burden projection for 2020 and 2040: a systematic review and meta-analysis. The Lancet Global health. 2014;2(2):e106–16.

Figure 7: Age-group specific prevalence estimates for (any) age-related macular degeneration (World Health Organization, 2019)

those with visual impairment have some level of vision (Lee et al., 2025; Vashist et al., 2017). In the figure below (Figure 6) the percentage of people in the Netherlands with visual impairments is shown per age group (women and men apart). Another interesting to see is how the prevalence of macular degeneration (the third most common eye condition, see Figure 8) increases with age as shown in Figure 7.

Leading causes

Globally, the primary causes of blindness in individuals aged 50 and older include:

- **Cataract:** 15.2 million cases
- **Glaucoma:** 3.6 million cases
- **Under corrected refractive error:** 2.3 million cases
- **Age-related macular degeneration**: 1.8 million cases
- **Diabetic retinopathy:** 0.86 million cases (Steinmetz et al., 2021).

In Figure 8 an overview of the prevalence of these causes is given. This visual reveals that the vast majority of visual impairments are caused by cataracts, fortunately cataract surgery is possible and a safe and effective procedure (Cataracts - Symptoms and Causes, n.d.). Unfortunately the second most prevalent eye condition, glaucoma, is not reversible and can cause visual impairment and even blindness if left untreated (Glaucoma - Diagnosis and Treatment - Mayo Clinic, n.d.). There is a wide diversity in conditions and in symptoms of VIPs.

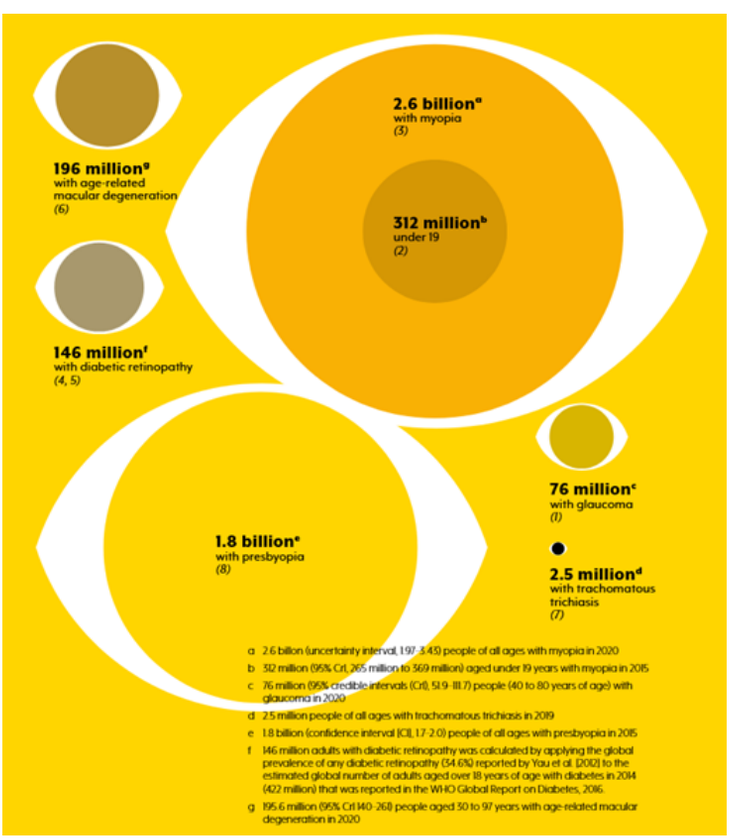


Figure 8: "Global estimates of numbers of people affected by selected eye conditions that can cause vision impairment" (World Health Organization, 2019)

Challenges for VIPs

Due to their conditions VIPs can face various challenges in their day-to-day lives. With suffering from different types of visual impairments, different types of challenges arise, it is important to keep in mind that visual impairment is an umbrella term for a range of different conditions or disorders. In Figure 9 a few of these different conditions are visualised.

These conditions and visual impairments can, among others, cause the following challenges:

- **Navigation:** Navigating to certain places can get difficult without being able to see (clearly), especially in less accessible situations. For example trying to take public transit where information is mainly communicated visually (Azenkot & Fortuna, 2010).
- **Daily living:** Visual impairment interferes with daily living, activities such as reading, driving, and watching TV (Lee et al., 2025).
- **Employment:** There are a lot of misconceptions about the ability of VIP's to work, therefore it can get difficult getting a job, while VIP's can be just as valuable in a company as a sighted person, especially with the right support (Dubay, 2023).
- **Acceptance:** Visually impaired or blind individuals often face challenges in accepting their disability, which can impact their self-esteem and social interactions (Vernon, n.d.).
- **Independence:** Achieving independence can be hindered by environmental barriers and societal attitudes, limiting their ability to perform daily activities and participate fully in community life (Remillard et al., 2023).

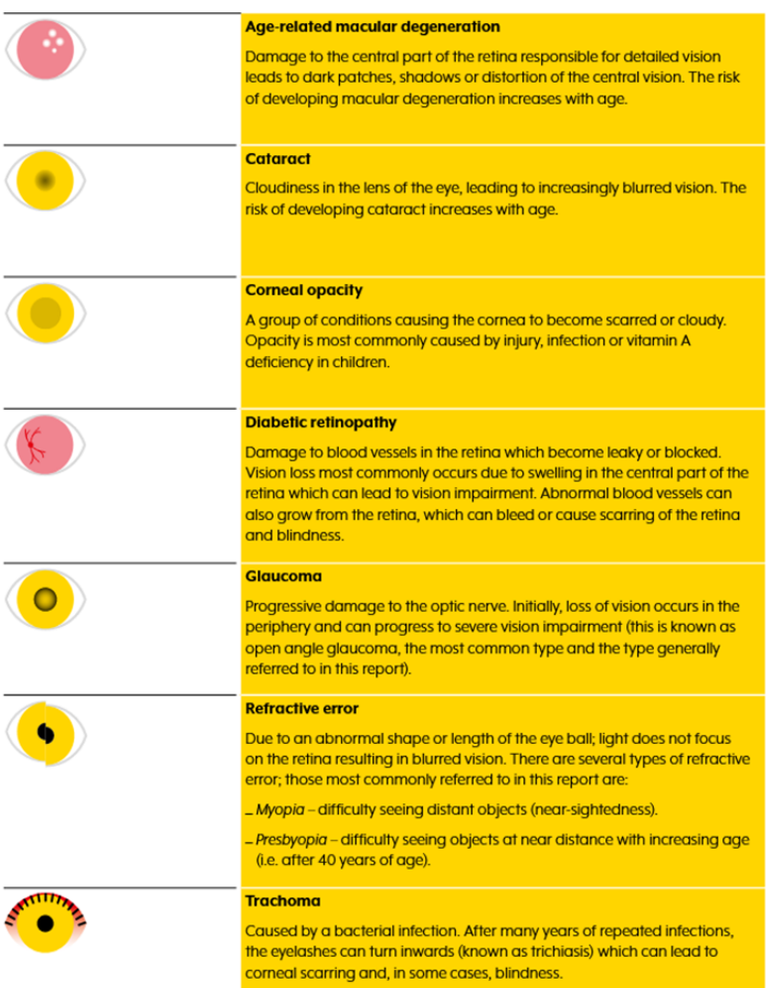


Figure 9: "Common eye conditions that can cause vision impairment including blindness" (World Health Organization, 2019)

2.1.2 Mobility impairment

Definitions

Mobility is defined as the ability of an individual to purposively move about her environment (Rosso et al., 2013). There are various types of mobility impairments, each leading to different degrees of disability.

The initial project brief defined mobility impairment as individuals who fall within the range of people that either should, could, or currently do use a rollator or walker. However, the brief was rewritten to include different mobility aids for MIPs that inhibit the free use of their hands. So, in this thesis the group of MIPs that will be referred to are all MIPs that use mobility aids that inhibit the free use of their hands

Prevalence

Approximately 1.3 billion people, or 16% of the global population, experience significant disabilities, many of which include mobility impairments (Y. Shimizu, 2023).

In the Netherlands, mobility impairments are particularly prevalent among adults. Data from a 2024 study indicated that 9.3% of the population aged 12 and above, experienced mobility limitations in 2023. This prevalence increases with age, with nearly one-third of women over 75 reporting mobility impairments. Additionally, 11.2% of people aged 55 and above face difficulties with activities of daily living (ADL), such as moving in and out of chairs or beds, and climbing stairs. These ADL limitations are most common among women over 75 as seen in Figure 10 (Plasmans et al., 2024).

Although in the Netherlands the percentage of the amount of people with hearing, visual and mobility disabilities decreased (Plasmans et al., 2024), it is expected that the overall number of people with disabilities will rise (Ageing and Disability | Division for Inclusive Social Development (DISD), n.d.). This will likely be because of the growing elderly population.
The global market for walkers and rollators was valued at $1.96 billion in 2024 and is projected to reach $3.23 billion by 2033, growing at a compound annual growth rate (CAGR) of 5.69% (Straits Research, 2024). This market growth suggests a solid and increasing number of individuals who currently use or could benefit from rollators.

However, specific data on the exact number of rollator users worldwide is limited. The increasing market size indicates a growing demand for such mobility aids, reflecting their importance in enhancing the quality of life for those with mobility challenges. As the market expands, it presents opportunities for innovation and the development of advanced rollators that better meets users' needs.

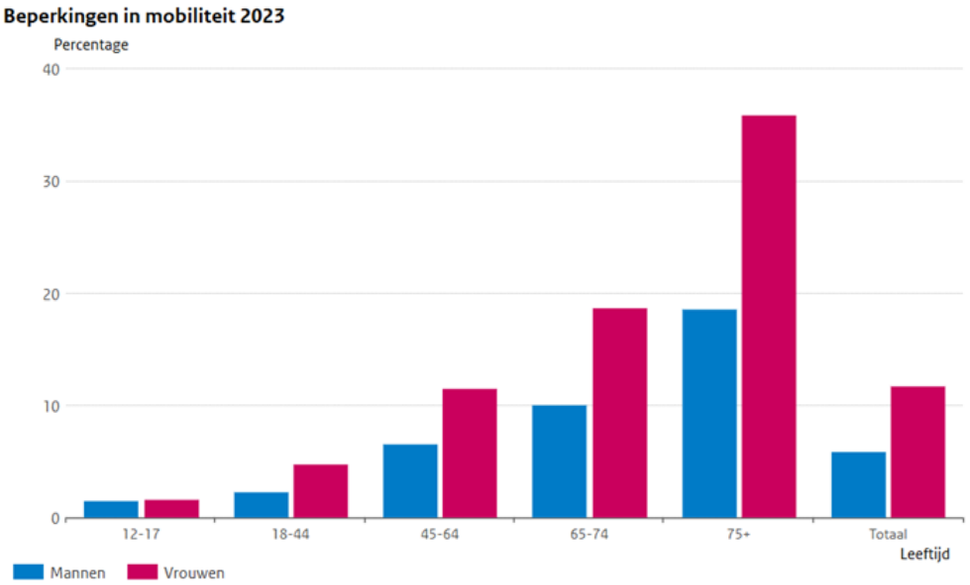


Figure 10: Limitations in mobility 2023 (Plasmans et al., 2024)

Leading causes

Mobility impairments arise from a variety of conditions that affect an individual's ability to move freely and comfortably. Neurological disorders (such as cerebral palsy, muscular dystrophy, Charcot- Marie-Tooth disease, ataxia-telangiectasia, spinal muscular atrophy, peroneal neuropathy and microvascular white-matter disease) can lead to gait disabilities. Electrolyte imbalances (including hyponatremia, hypokalemia and hypomagnesemia) may disrupt neuromuscular function, resulting in gait disorders. Vitamin deficiencies (particularly in folate, vitamin B12, vitamin E and copper) can cause neurological dysfunctions that prevent proper gait. Other contributing factors are pain, vascular issues, traumatic injuries, autoimmune conditions, inflammatory diseases, metabolic disorders, neoplastic conditions, paraneoplastic syndromes, and tabes dorsalis (Ataullah & De Jesus, 2025). Additionally, the prevalence of mobility impairments increases with age, thus making this target group extra relevant in an aging population (see Figure 11).

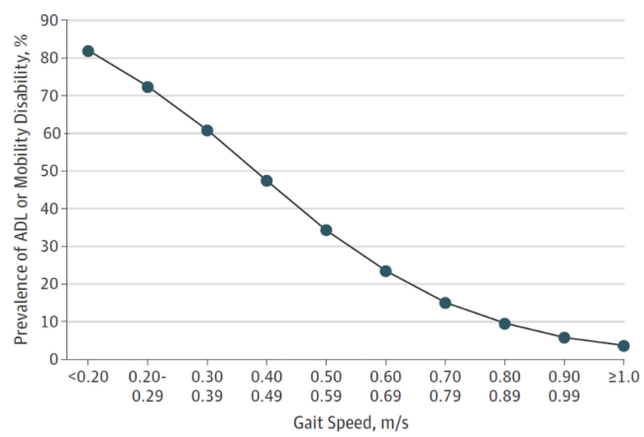


Figure.
Prevalence of Either Disability for Activities of Daily Living or Mobility Disability by Usual Gait Speed Among Men Aged 80 Years (N=6534)
ADL indicates activities of daily living. Based on data from Guralnik and colleagues.[10]

Figure 11: Immobility increases with age (Cummings et al., 2014; Freiberger et al., 2020)

Leading causes

Mobility impairments arise from a variety of conditions that affect an individual's ability to move freely and comfortably. Neurological disorders (such as cerebral palsy, muscular dystrophy, Charcot-Marie-Tooth disease, ataxia-telangiectasia, spinal muscular atrophy, peroneal neuropathy and microvascular white-matter disease) can lead to gait disabilities. Electrolyte imbalances (including hyponatremia, hypokalemia and hypomagnesemia) may disrupt neuromuscular function, resulting in gait disorders. Vitamin deficiencies (particularly in folate, vitamin B12, vitamin E and copper) can cause neurological dysfunctions that prevent proper gait. Other contributing factors are pain, vascular issues, traumatic injuries, autoimmune conditions, inflammatory diseases, metabolic disorders, neoplastic conditions, paraneoplastic syndromes, and tabes dorsalis (Ataullah & De Jesus, 2025). Additionally, the prevalence of mobility impairments increases with age, thus making this target group extra relevant in an aging population (see Figure 11).

Challenges for MIPs

Individuals with mobility impairments face a multitude of challenges that affect various aspects of their lives:

People with mobility impairments deal with all kinds of challenges that affect their daily lives as well as independence as overall well-being. In the following section these challenges will be discussed to gain better insight into the world of mobility impaired persons (MIPs).

- **Physical barriers:** these could include all types of hindrances on the road, like stairs and rough or slippery terrains
- **Transportation limitations:** when being less mobile, independent travel could become more of a challenge. This could be because people cannot operate vehicles or have a hard time entering public transportation due to gaps for instance.
- **Social barriers:** some people experience negative perceptions and biases from others that could lead to discrimination, social exclusion, which could eventually impact self-esteem and mental health.
- **Health concerns:** the issues MIPs face could lead them to secondary health issues like obesity, pain and a higher prevalence of mental health conditions like depression and anxiety (Iezzoni et al., 2001).
- **Financial implications:** due to the lack of access to suitable job opportunities and expensive assistive devices that cause additional costs, MIPs could struggle with getting their finances in order.
- **Education:** Inadequate educational structures could negatively impact the quality of life for MIPs. This could be in the form of physical inaccessibility (stairs, no lift or ramps, long walking distances between classes) or psychological (e.g. awareness, bullying and different treatment) (Challenges for People with Disabilities, n.d.; Zo maak jij de school toegankelijk voor fysiek beperkte kinderen, n.d.).

2.1.3 Having both walking and visual impairments (MVIP)

QUOTE

"Lack of independent and safe mobility is ranked as the most significant barrier depriving individuals with visual impairment of a normal living experience"

~ (Bujacz et al., 2008; Hakobyan et al., 2013).

The target group has both visual and mobility impairments and therefore experiences the cumulative of the challenges these groups face and more. These challenges will be further discussed in chapter 2.3 Current situation.

Prevalence

In Figure 12 the number of disabilities (in hearing, seeing or mobility) per person are shown. Because in this graph people with hearing disabilities are also considered, and this is not within the scope of this project, some clarification is needed. It is hard to find the exact number of people with both hearing and mobility impairments. But what can be deduced from this graph is that at least 0.6% of people in the Netherlands older than 12 years is an MVIP, and a maximum people of 2.2%. What also can be seen is that min. 1.8% and max. 6.7% of people over 75 years old are MVIP's. In 2022 the Dutch population of 12 years and older is 15.497.063 people (Age Distribution, n.d.). That would make a target group of about 93.000 people in the Netherlands alone. If we were to take these numbers as the same for the world population (approximately 6,571,215,000 people would be older than 12 years today (Population.Io, n.d.)), with a target group of about 40 million people that are MVIP.

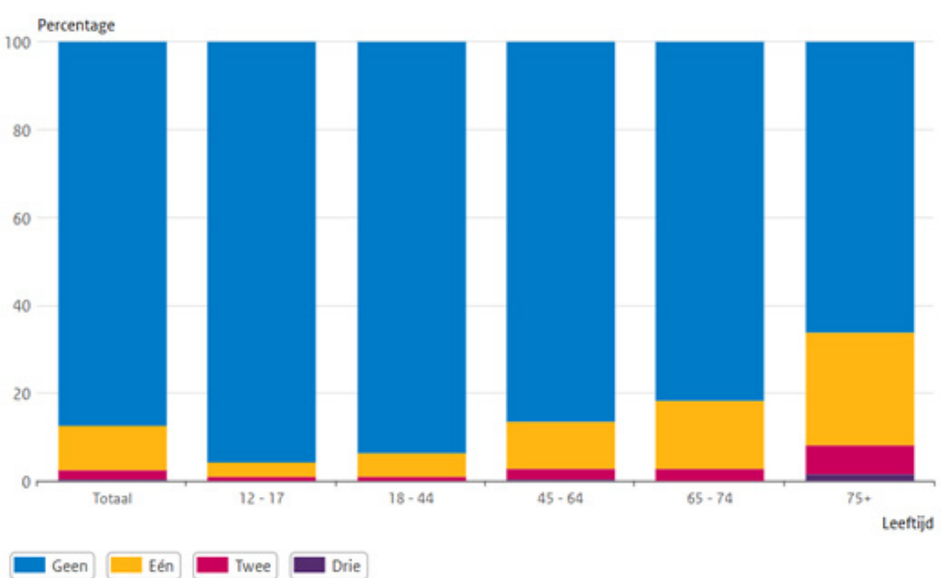


Figure 12: Amount of disabilities in functioning 2023 (Plasmans et al., 2024)

Elderly

The biggest portion of the target group is elderly people. Because the population is aging it should be noted that the target group is only getting bigger, and with that the need for a solution to help MVIPs have access to independent and safe mobility.

Especially elderly people have more need for this solution as their challenges grow bigger with age, challenges like loneliness and fitness for example. This is visualised in Figure 13 by showing the limitations in ADL.

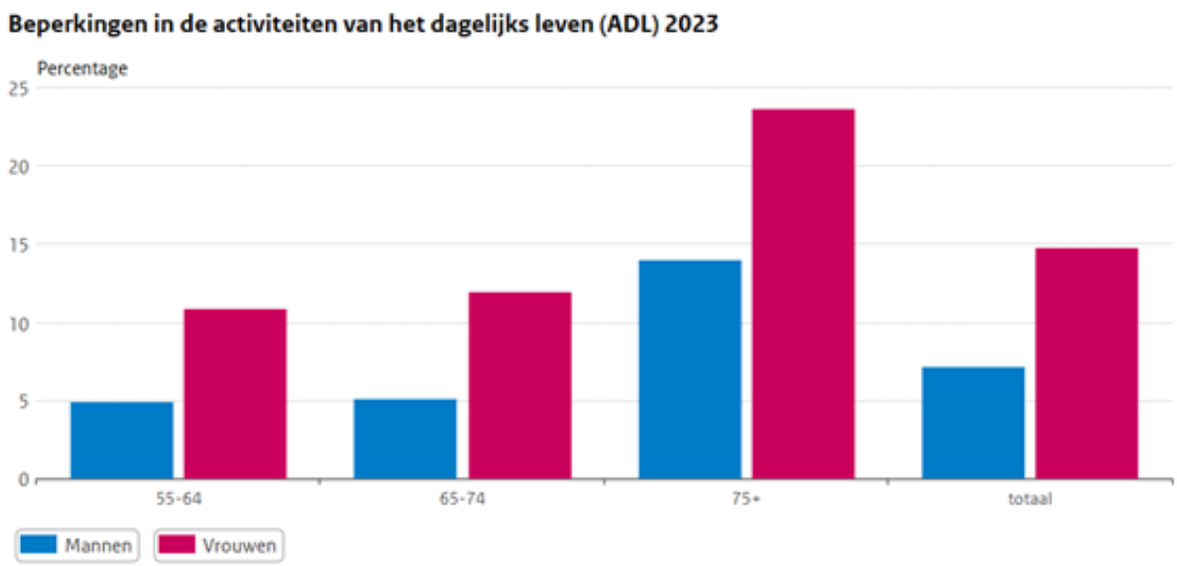


Figure 13: Limitations in activities in daily life (Plasmans et al., 2024)

2.1.4 Key points: Target group

Diversity:

- Important to note is that visual impair ments and blindness can mean very different things from person to person. The different conditions can cause tunnel vision, blurriness, spots and more. This diversity should be taken into account during the design phase.The same holds for people with mobility impairments. The target group has generally the same implications but is still very diverse. Therefore, a 'one size all' solution will most likely not be the ideal solution, as one can still make use of useful abilities while others can't. It would be nice to let the user use these abilities as much as possible and only support them where it is necessary.

Mobility:

- People that need a rollator will also be more prone to have joint problems or other conditions that cause them not only to be supported in walking but also for instance in gripping or supporting their weight on the handles (ergonomic grips).

Aging population:

- During this analysis it became apparent that a vast majority of the target group consists of elderly people. It is important to take this in mind during designing.
- This means symptoms will most likely in a lot of the cases only worsen, so it might be interesting to see if the amount of support could grow with the user.
- Elderly people have various conditions, so MVIPs might also have a higher likelihood to have other conditions that affect their hearing or cognitive functions (e.g. dementia).

Secondary conditions:

- Finding a good solution to the problems that MVIPs face in terms of mobility could prevent secondary conditions like obesity and social exclusion, as this would help them stay active and help go outside.

2.2 Market and domain analysis

2.2.1 Related work

The idea of creating a mobility solution for MVIPs as well as the necessity for a solution has been around for a long time. A substantial body of research has already been dedicated to this specific topic. To visualize this work, a timeline was made with relevant and related works of other people (see Figure 14) (A list of all papers can be found in Appendix A: Related research).

Reflection on related work

What is striking is that there has been extensive research into the subject of this thesis, but nowhere on the market can a successful solution be found. The question is, why not? There seems to be a high potential for a solution to the problem, the right technology is available, there are enough potential customers, and the market is growing towards more luxury products in the mobility aid segment. Could it be that this project comes at just the right time, after the Covid-19 pandemic, when the right technologies are affordable and accessible enough? This question remains unanswered, but perhaps it will become clearer as the project progresses.

What is interesting to see is that the LEA robot, a very advanced product that gained a lot of attention, awards and subsidies (LEA Lean Empowering Assistant Care Robot, n.d.), went bankrupt in 2020. This was because they neglected some of the prime user requirements, like weight and cost. The product cost an astonishing 9980 euros or with a lease 237 euros per month. Not only was the product very expensive it was also quite heavy (43 kg) and because of all the functionalities the product had a high cognitive load (Jongejan, 2018, 2022).

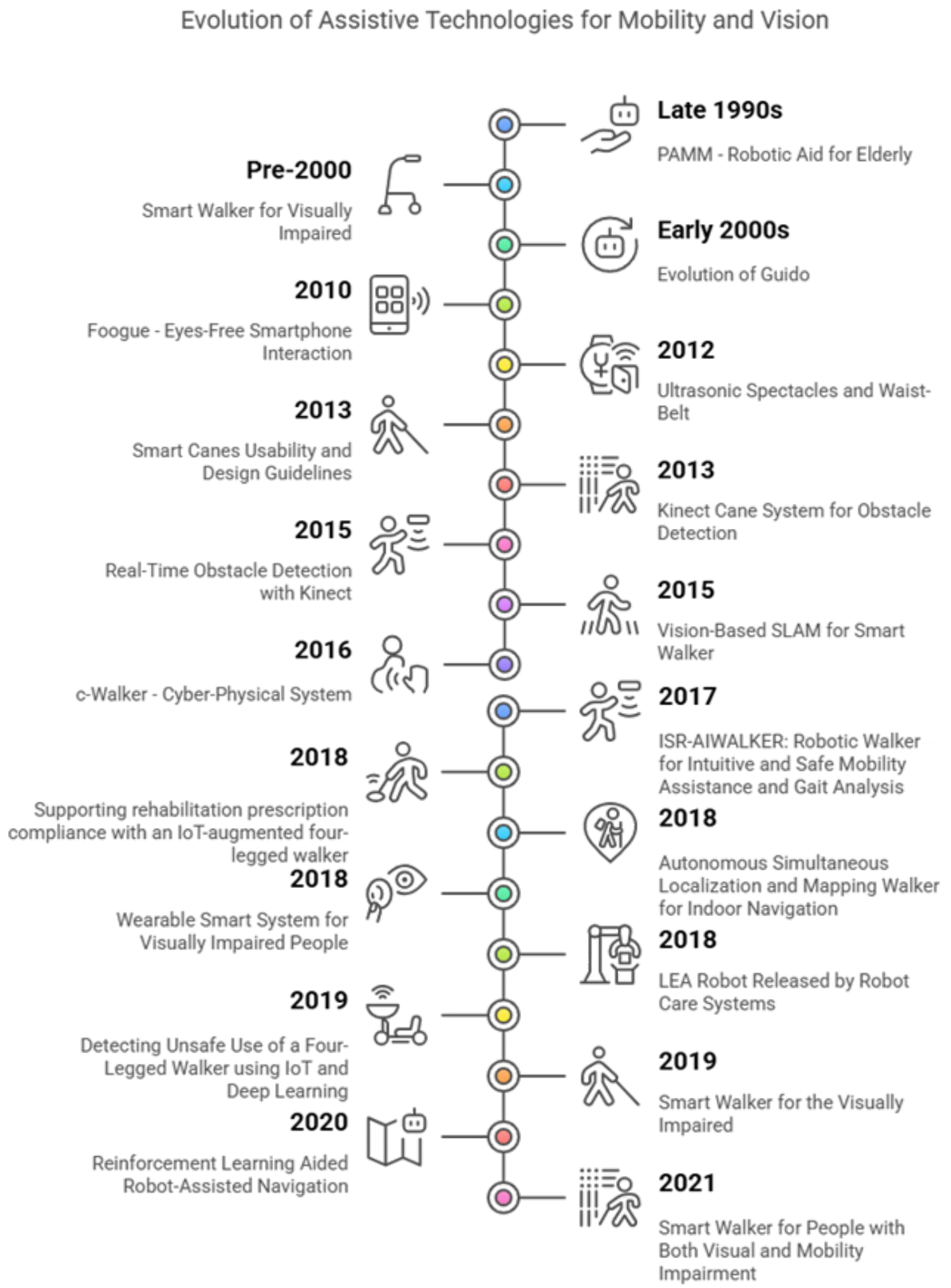


Figure 14: Timeline of related work

2.2.2 Technology

In the following chapter, technologies that might be promising for this project will be discussed. Here technologies for sensing the environment, processing the information that was gathered, and user interface technologies are discussed.

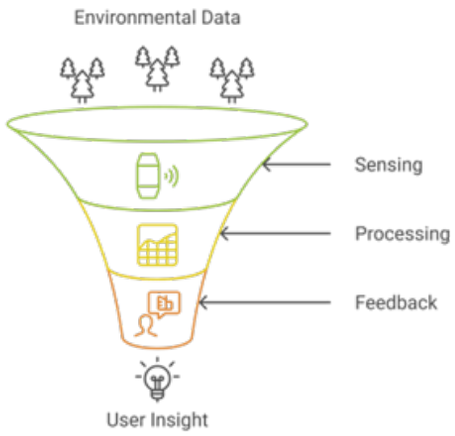


Figure 15: Data flow

Sensing technologies

To ensure the user gets the right message it is important that the system has an accurate enough understanding of the possible obstacles on the user's path. Here the most promising and/or most used technologies for sensing the environment will be discussed.

- Ultrasonic sensor (Bhatlawande et al., 2012; Chaccour et al., 2015; Geol Kim et al., 2016; Mazhari & Paramytha, 2023): Ultrasonic sensors emit high-frequency sound waves, these bounce back to the sensor and the system measures how long it takes for the sound to reflect back on the sensor. This technology is very effective at short ranges. This technology does have some complications, It cannot necessarily detect where the object is in the space with a single sensor, only if there is an object and how close it is, this is because of unidirectional distance measuring (Liu et al., 2024). The technology also presents some difficulties when working with multiple sensors at once because of interference. The sensors are also prone to environmental conditions, making them difficult to use outside.
- Infrared sensor: This is an electromagnetic wave with a wavelength between visible light and microwaves. An infrared sensor system emits an infrared beam that reflects back to the sensor. This system is similar to the ultrasonic sensor and consequently has similar implications. Infrared is just like ultrasonic, a reflective and unidirectional system which makes it difficult to get a 3D image of the environment.
- LiDAR (Light detection and ranging) (Kashyap et al., 2018): Light detection and ranging (LiDAR) is a system working with the time of flight principle, it sends out lots of light lasers that bounce back off objects. Measuring the time it takes for the light to return back to the receiver it makes an accurate 3D map of the world around it. LiDAR has a more detailed output than radar for instance. Because of this LiDAR is used a lot in autonomous vehicles. But, Li-

DAR is expensive and works less well in foggy or dusty environments (What Is LiDAR and How Does It Work?, n.d.). On the other hand, LiDAR is a rapidly evolving technology which could bring the cost down very quickly in the coming years. There are already some advancements going on making them significantly cheaper (around 200 USD) ('Exclusive', 2024).

- **Radar** (radio detection and ranging): Radar uses the same principle as LiDAR but uses radio waves instead of light pulses. Radar is commonly used in the automotive industry for detecting obstacles and in adaptive cruise control (Engelsman, n.d.). Radar provides quite a rough image and could have difficulties detecting objects not directly reflecting back to the receiver. An advantage of radar technology is that it works very well in outside environments, including in foggy, light, dark, or dusty situations. Radar technology is also on the more expensive side, coming in between the cost of LiDAR and RGB-D cameras at around 100 - 400 USD per unit).
- **Cameras:** RGB-D cameras are able to collect both colour (RGB) and depth (D) information. Using this spatial data, a map of the environment is created. The camera captures depth using two different cameras apart from each other, layering these images the differences between the corresponding pixels is calculated and with that information the depth can be measured. Because sometimes these pixels can be difficult to identify, for example on a white wall, an infrared dotted pattern generator can be added to overcome this problem, emitting a dotted pattern in the space and capturing the size of these dots, these problematic areas can be mapped as well (Saha et al., 2022). A well-known application of this technology was the Microsoft Kinect camera used as an add-on for XBOX gaming consoles, making it possible for the console to read what movements the users are making. This technology is less accurate and difficult to use in outside environments, on the other side is this technology much cheaper than the other sensor technologies (Kinect Sensor Xbox 360, n.d.).

Though each of these sensors could be promising, an outcome using a multitude of these sensors would be probable as in the automotive industry as well as similar projects multiple types of sensors are used (Kramer et al., n.d.; What Is LiDAR and How Does It Work?, n.d.). Another thing to consider when choosing a sensing technology is that ToF- sensors are only able to sense objects that the signal they send out can bounce back from, so a potential hole or canal is harder to detect.

Processing technologies

To store and transfer all the data that is used it is important to have the right processing mechanisms. A selection of these processing methods will be discussed here.

To collect, store, translate and transfer all data the system needs some type of computer(s). Some of these technologies described in the previous section come from the factory with the needed computing systems to offer easily readable and usable data.

There are little similar products on the market already and a lot of the previous work done on the topic of mobility aids for MVIPs used temporary solutions. Laptops and power supplies carried in backpacks for instance (Orita et al., 2013; Pham et al., 2015). Regarding processing several approaches can be considered, mainly differing the distance to the product of where the data is being processed. Figure 16 gives an overview of the different general approaches.

- Local storage and processing: This is the fastest way of processing data, there are direct pipelines where data flows through and is directly translated inside of the product to usable information for the user. This real-time process is needed in situations where delays can lead to decreased effectiveness or missed opportunities, for instance in autonomous vehicle navigation. There are some limitations to real-time processing, like limited support for complex calculations and higher costs (How Much Does Real-Time Data Processing Cost for Businesses?, n.d.; 'How Real-Time Data Processing Revolutionizes Autonomous Functions', 2024).
- Edge computing: Edge computing is one step further away from the product but as close to the product as possible and still considered to be real-time processing. Edge computing processes the data on local devices or edge serv-

Figure 16: Data flow

ers (Yeung, 2022). This process is considered very fast and real-time processing, but can be slower than a built-in processing unit.

- **Cloud based processing:** Cloud computing is a way of processing the data in the cloud. It is a scalable and flexible approach to processing. Cloud computing adoption is increasing because of several reasons including, lower initial costs, easy updating and reliability.

Besides the choice of where the data is processed, a look can also be taken at how this type of data can be processed. The most widely used method for this is **Simultaneous Localization and Mapping** (SLAM). SLAM is a computational process or algorithm where a device can map the 3D environment that it is in while simultaneously determining where in the environment it is positioned. This technology can process data from sensors like cameras, LiDAR and sonar. Another technology that would be able to process data is **artificial intelligence** (AI), ready to use object recognition algorithms and object databases can be used for free (Ustc-Community/Dfine-Nano-Coco · Hugging Face, 2025).

User feedback technologies

Considering this project the interaction between the product and the user could be described as the 'do or die'-function of the desired product. That is one of the reasons that good research for the possibilities of this is important. Interfaces are mainly visual, this means that most of the interfaces available are not or less accessible for VIPs. In this section alternatives to graphic interfaces (GIs) are discussed. Because the visual sense is less or unavailable for VIPs, the interface will have to interact with the other senses of the user, mainly concerning the touch (haptic) and hearing senses.

During a brainstorm session (see Appendix B: HKJ's) different ways of getting information to the user can be categorized. These ways can be divided in the different senses that are still available to MVIPs. These senses are; taste, hearing, smell and touch. Figure 17 shows the estimated bandwidth of the senses. From this figure it becomes clear that the second largest amount of data is coming in by the touch sense.

The use of the touch and hearing senses are the most common in the related research, ranging from haptics, texture (braille), sonification, speech and even tongue display units (TDU) (Azenkot & Fortuna, 2010; Hakobyan et al., 2013; Khusro et al., 2022; Pham et al., 2015; Treml, 2018).

Vibration patterns to translate information to the user. Based on dimensions using a natural pattern somewhat representing the fitting action. These patterns are used in a bit pattern based on morse code (Khusro et al., 2022). In this paper there are three types of feedback mediums - voice, sonification and

vibration - discussed. Each has their pros and cons. Voice feedback is not suited for noisy environments and has a high level of disturbance. It is also privacy sensitive. Sonification feedback is the use of sounds to convey information. Sonification does not have the privacy implication that audio feedback has but is also not suited for noisy environments, additionally sonification is prone to have a high cognitive load. Vibration feedback, a form of haptic feedback where information is conveyed using vibrations to the user, does not have the privacy implication as well as the noisy environment complication, but vibration feedback can also increase the chance of high cognitive load.

Digital support for MVIPs

One of the goals of this project is to integrate digital support to offer the user a central place to interact with the system, similar as what was done with the Rollz Rhythm (Rollz Motion Rhythm rollator voor Parkinson, n.d.). This app could be used to change the settings of the product, give additional information, data storage and processing, user history, tracking activity and so on. This app could be used by the user, caregivers or any other support healthcare personnel.

There are several ways to make an app accessible for VIPs. A promising technique is the Slide Rule, the slide rule describes a way for blind people to navigate touch screens by sliding a finger around on the screen and by the app reading aloud what 'button' the user is hovering on, by double tapping anywhere on the screen the last read button is clicked (Kane et al., 2008).

Other techniques for eyes free interfaces are gestural recognition and text to speech (TTS). Where gestural recognition is more difficult to implement in an app interface while TTS is already integrated in the Slide rule.

In an interview with someone from the Koninklijke Visio, it became apparent that there are people specialized in app design for VIP's that would be able to assist during the development of the app.

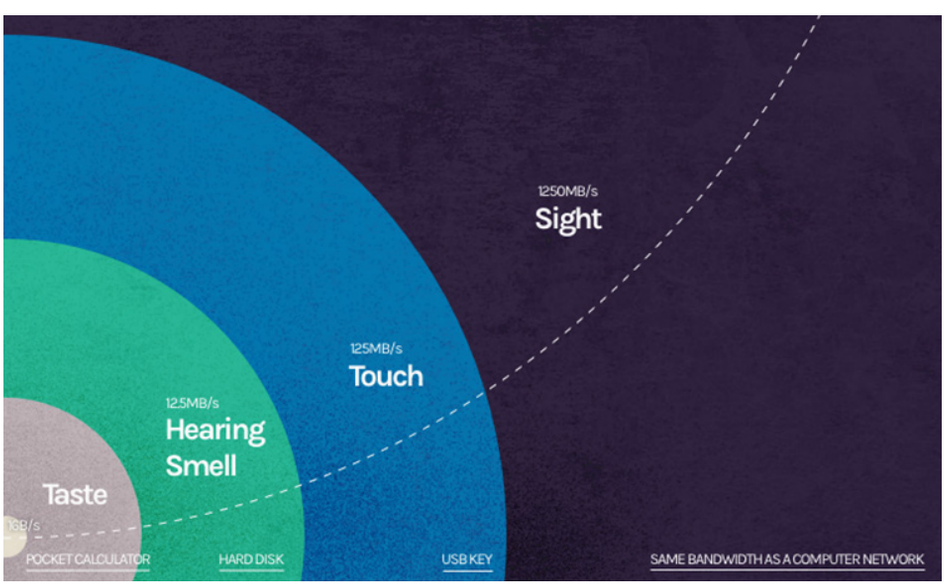


Figure 17: "the bandwidth of senses" (Tor Nørretranders, 2015)

Artificial Intelligence in mobility

Like a lot of innovative technologies from this decade, today's world without artificial intelligence (AI) is unthinkable. As for the development for innovative rollators, this thesis would be incomplete without involving this new type of modern technology. For rollator technology the most relevant applications of AI would be self-driving software, (additional) safety, live terrain navigation, self-adjustments and biometrics. Companies like GlüxKind are already setting an example of what AI technology can mean for stroller innovation. They use a mix of navigation and self-driving technologies, and aim to make strollers more comfortable for busy parents (Glüxkind AI Stroller - The Best Smart Stroller for Your Family, n.d.).

Some examples of AI implementations for this project are;

- Object recognition, using a camera the product could sense the environment being able to provide the system with useful environmental data.
- Smart connections, while using the product the rollator learns more about the user and adapting its functions to best suit their operator
- Smart sensors that can scan the terrain and can calculate routes that the user can take around possible obstacles, similar to smart driving sensors being able to navigate while surrounded by vehicles or other obstacles
- An integrated smart assistant, with abilities like reminders, live navigation, holding conversations and more
- Smart braking systems that can take over when the user is in danger.

Additional interesting applications of AI for this project are discussed in the synthesis section later on in this report.

Integrating AI into rollator designs for individuals with visual impairments offers potential to enhance mobility and independence. However, this integration entails various design considerations across safety, environmental impact, product complexity, and costs.

Safety

One aspect of AI functionalities in rollators are the safety considerations. While AI has the potential to enhance mobility and independence, its application in autonomous navigation systems has encountered several challenges. For example, a study on smart walkers equipped with depth-sensing cameras revealed that while these devices could detect obstacles, they also produced false positives, leading to confusion and slowed reactions among users (Feltner et al., 2019). Additionally, the complexity of AI systems can result in technical malfunctions or software errors, causing sudden stops or unintended movements that pose risks to users.

Over-relian ce on AI navigation may also diminish users' situational awareness, making them vulnerable if the system fails. While AI offers promising enhancements for assistive mobility devices, the safety concerns observed in autonomous navigation systems suggest caution. Prioritizing user safety calls for addressing these challenges before fully integrating AI-driven autono-

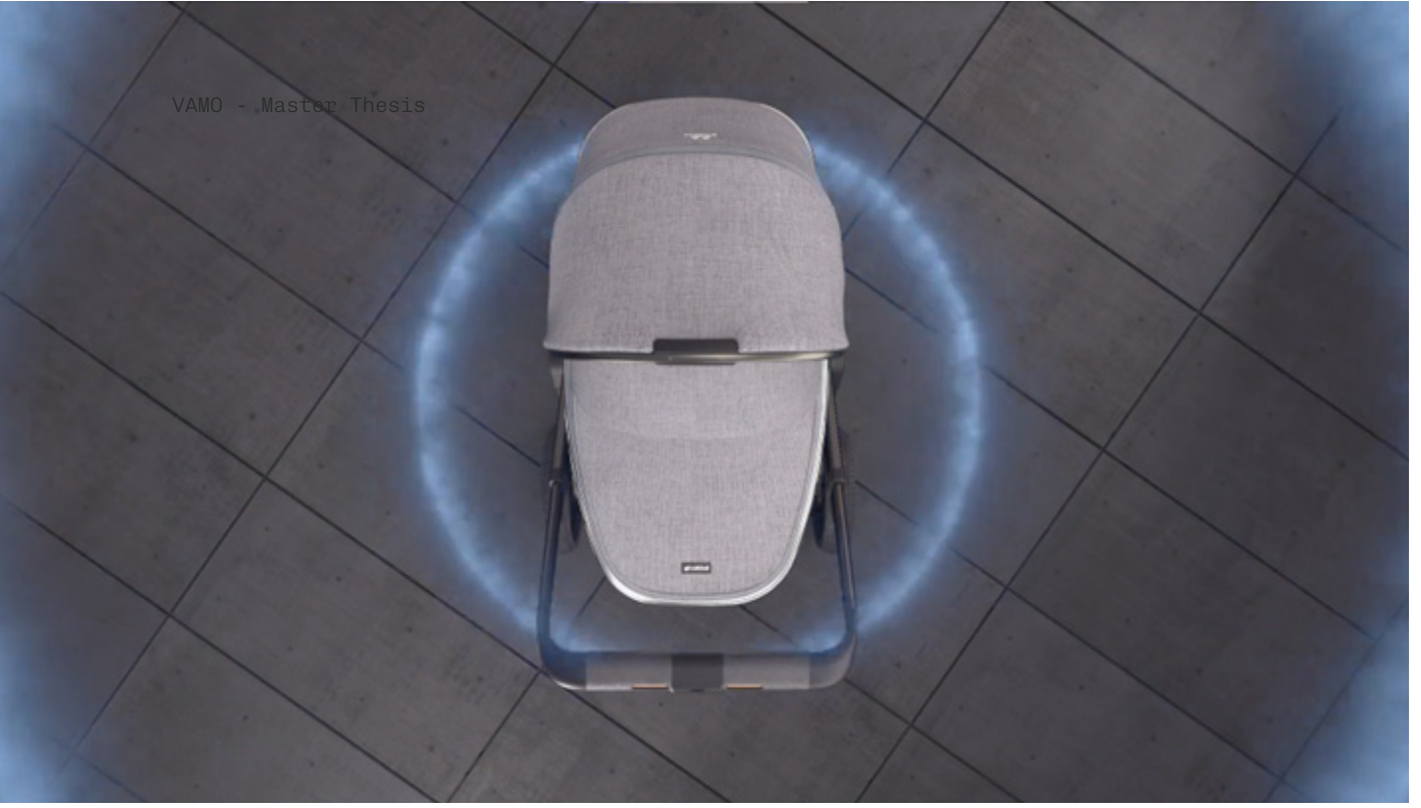


Figure 18: Glüxkind AI Stroller (Glüxkind AI Stroller - The Best Smart Stroller for Your Family, n.d.)

my into walking aids. Due to these safety implications, the general public tends to still be hesitant in implementing operational AI in their vehicles (Alaniz, 2024).

Environmental

The effects of AI on the environment still remains unclear, but it is certain has a significant impact (Delort et al., n.d.; Digital Economy Report 2024, 2024). With environmental implications becoming more prominent, it is important to keep asking the question; 'Is AI necessary for this product to function as intended?'.

Complexity

Incorporating artificial intelligence into rollators introduces increased product complexity, including hardware and software components. The integration of sensors, processors and AI algorithms asks for a highly detailed design approach to ensure that operation and user interaction work as intended. For instance, AI powered assistive technologies require well-structured data processing capabilities to analyse environmental inputs and to be able to provide the user with real-time feedback. This complexity can lead to challenges in development, maintenance and user training. To overcome this challenge luckily large language models can also help speed the development up (if used responsibly) and there is already a lot of open source code and data available to offer a steady base (Ustc-Community/Dfine-Nano-Coco · Hugging Face, 2025).

Costs

Considering all these above-mentioned topics, costs can pile up fast, e.g. safety tests, complex systems, AI expertise, (possible) environmental charges and a highly elderly target group not familiar with technology. However, as AI tools become more accessible and modular, their integration into assistive devices like rollators holds great promise for affordable and scalable innovation.

2.2.3 Trends in mobility aid sector

Recent advancements in mobility aids, including rollators, have focused on improving functionality, personalization, and accessibility for users. Several key trends have emerged, shaping the development of mobility solutions, though specialized rollators for individuals with visual impairments remain largely underdeveloped.

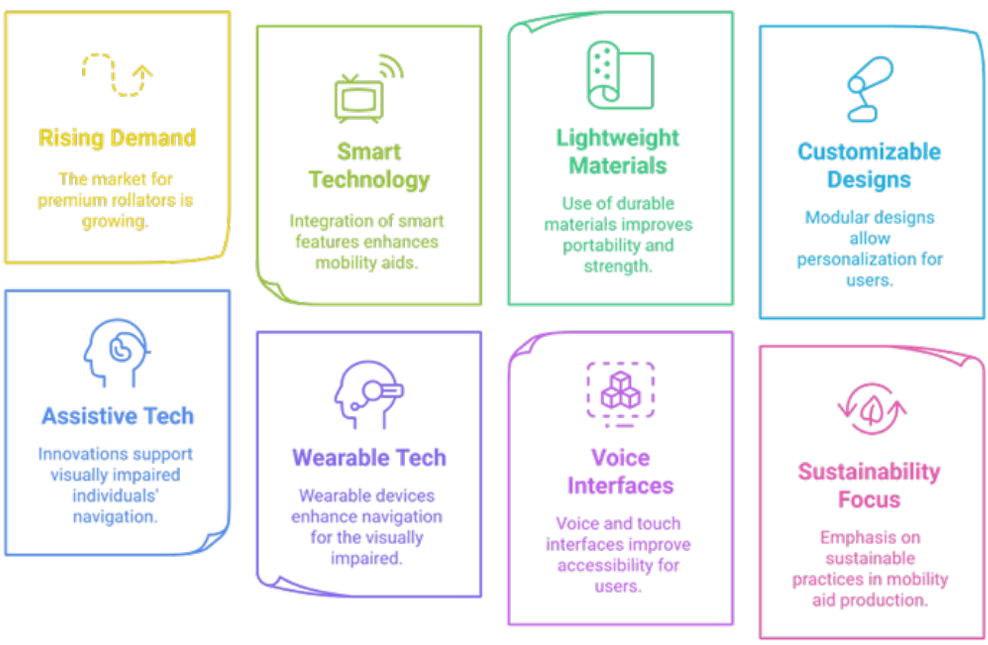


Figure 19: Overview of trends in mobility aid sector

Rising demand for premium rollators

Recent market analyses indicate a noticeable shift toward premium mobility aids, including high-end rollators. The global rollator walker market was valued at approximately $76.21 million in 2023 and is projected to reach $126.58 million by 2032, reflecting a compound annual growth rate (CAGR) of 5.8% from 2024 to 2032 (ltd, 2024).

Similarly, the broader mobility aids and transportation equipment market is expected to expand from $7.25 billion in 2025 to $13.23 billion by 2035, with a CAGR of 6.2% (Mobility Aids & Transportation Equipment Market 2025-2035, 2025).
This growth is driven by an aging population, increased prevalence of mobility-related health issues, and a rising willingness among consumers to invest in durable, high-quality mobility solutions that offer enhanced comfort and functionality. Consequently, companies are experiencing increased demand for their premium rollator designs, as consumers seek products that combine luxury with practical support.
Integration of smart technology
Connectivity with other devices has become an essential aspect of modern mobility aids. Many mobility devices and even some rollators are now equipped with smart technology, enabling integration with smartphones and other digital tools (see

Figure 20). This connectivity allows users to monitor health conditions, customize their device settings, and enhance safety through real-time navigation assistance (The Latest Technological Advances in Mobility Aids, 2023; Verdezoto et al., 2022). Additionally, the implementation of touchless input methods, such as air gestures, is gaining traction, allowing for more seamless interaction with assistive devices (Chiu & Stafford, 2024).

Figure 20: Smart app with rollator (Rollz Motion Rhythm rollator voor Parkinson, n.d.)

The integration of sensors and actuators has enhanced the safety and functionality of mobility aids. These sensors can detect obstacles, assess terrain conditions, and provide essential environmental data for improved navigation. Earlier versions of smart rollators relied on traditional input methods like touchpads and joysticks, but newer designs incorporate onboard sensors, such as force sensors and load cells, to determine user intent based on how they interact physically with the device. Some models also feature voice control for greater accessibility, though cost remains a limiting factor. Additionally, modern rollators employ shared-control and autonomous-human operation modes to enhance stability and adapt assistance to user needs, minimizing balance loss and optimizing trajectory support (Verdezoto et al., 2022). Adaptive features like automatic braking and stabilization mechanisms further improve safety and user confidence (The Latest Technological Advances in Mobility Aids, 2023).

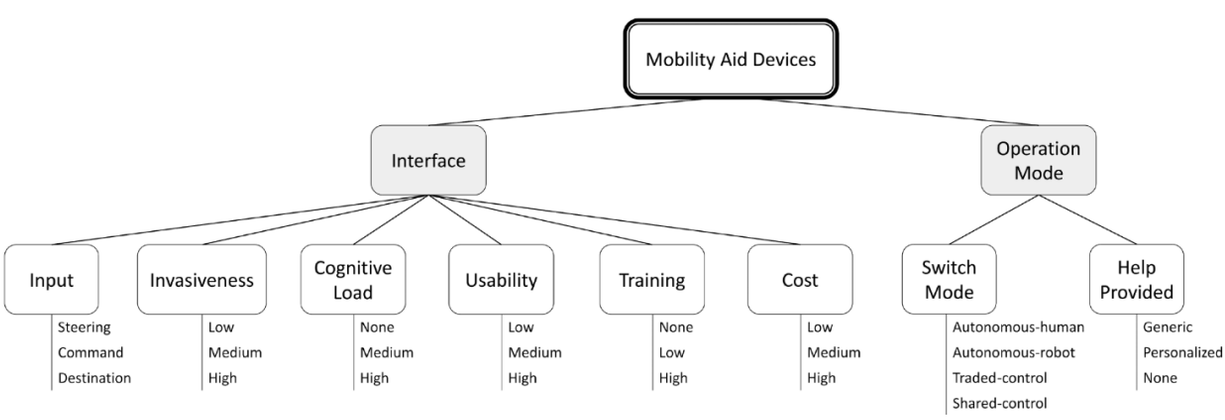


Figure 21: 'Mobility aid devices taxonomy for smart rollators' (Verdezoto et al., 2022)

Use of lightweight and durable materials

The use of lightweight and robust materials, like aluminium and carbon fibre, has been changing the world of mobility aid designs. These materials enhance portability and ease of use while maintaining durability and strength. This shift toward user-centric design prioritizes both functionality and user comfort, making devices more adaptable to different mobility needs (The Latest Technological Advances in Mobility Aids, 2023).

Customizable and modular designs
The shift towards a more user-centric mindset also means that devices are increasingly being designed with customization and modularity in mind. Adjustable seating, ergonomic handles, and modular components allow users to tailor their devices to their specific needs. The devices can grow to the user's needs and grow with them during their life. This not only extends the lifespan of the devices but also enhances overall user satisfaction. Rollators can now be equipped with modular add-ons such as storage compartments, navigation assistance systems, and even voice controlled features for enhanced accessibility (The Latest Technological Advances in Mobility Aids, 2023; The Sustainable Rollator | ROLLZ, n.d.).

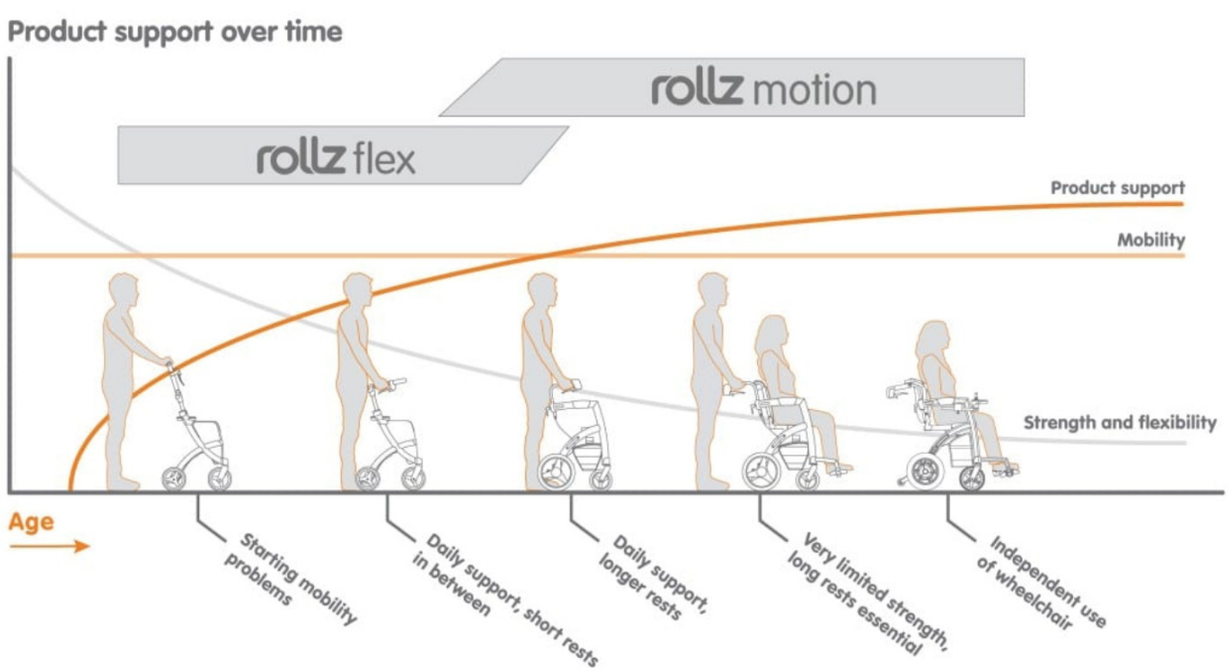


Figure 22: Adaption of Rollz to patient (The Sustainable Rollator | ROLLZ, n.d.)

Development of assistive tech for visually impaired people

Innovations in assistive technology continue to support individuals with visual impairments. Screen-reading software, magnification tools, and refreshable braille displays are improving accessibility. Additionally, multisensory developments, such as auditory guidance, air gestures and haptic feedback, are being integrated into mobility aids to assist with navigation and spatial awareness (Assistive Technology Products | American Foundation for the Blind, n.d.; Chiu & Stafford, 2024).

Voice-activated and touch-based interfaces

The rise of virtual assistants and smart speakers creates a new type of interface for VIPs. In addition to the voice-activated interfaces touch based interfaces are also getting more attention. For instance, the slide rule was developed to allow customers to use touch-screen devices without needing visual feedback (Kane et al., 2008). Because of this VIPs can interact with mainstream devices more intuitively and efficiently (A to Z of Assistive Technology for Low Vision, n.d.).

Advancements in wearable technology

Wearable technology is advancing, which is improving navigation for visually impaired individuals. Devices such as smart glasses, head-mounted cameras, and magnifying wearables provide real-time environmental feedback, helping users navigate their surroundings more effectively. These technologies, like the IrisVision headset and Orcam MyEye, enhance remaining vision and read text aloud, while systems like NaviLens offer step-by-step directions in public spaces (Wearable Tech, n.d.).

Focus on sustainability

Sustainability has become an important factor in the development of mobility aids. Manufacturers are adopting sustainable materials and production processes to reduce environmental impact. Additionally, the second-hand market for mobility aids is expanding, allowing individuals to buy and sell pre-owned devices, making them more financially accessible while promoting sustainability (The Sustainable Rollator | ROLLZ, n.d.).

2.2.4 Safety and Regulations

This chapter discusses the safety and regulations for visually impaired individuals in the Netherlands, as this is the scope of this project. It covers the traffic rules that apply to people using white canes and rollators, as well as the legal requirements for visually impaired individuals operating different types of vehicles. In addition, it looks at financial support for mobility aids. While the focus is on Dutch regulations, there is also a brief comparison with laws in other countries to provide context.

Participating in traffic as a VIP

According to the Dutch Traffic Regulation Article 49, paragraphs 1 and 2, pedestrians using a white cane or those who move with difficulty always have the right of way. As a driver, you are required to yield to pedestrians and operators of disabled vehicles (including those using rollators) when they are crossing or about to cross at a zebra crossing (Burg, 2023). For blind and visually impaired individuals, specific crossing techniques have been developed (see Figure 23), although these techniques are not legally mandatory.
In the Netherlands, the term "blindenstok" (white cane) refers to a recognition or tactile cane featuring one or more red stripes. Regarding the operation of vehicles, such as walking, cycling, or driving a mobility scooter, moped, microcar, or a similar vehicle, there are no minimum legal vision requirements. Visually impaired cyclists are not obligated to display an SZ (abbreviation of visually impaired in Dutch) sign. However, for mopeds, microcars, and scooters, an AM driving license is required.
Furthermore, if a (visually impaired) person wishes to drive a car or tractor, they must obtain a B or T driving license, respectively. The legal provisions governing these requirements are detailed in (appendix C)(Burg, 2023) .

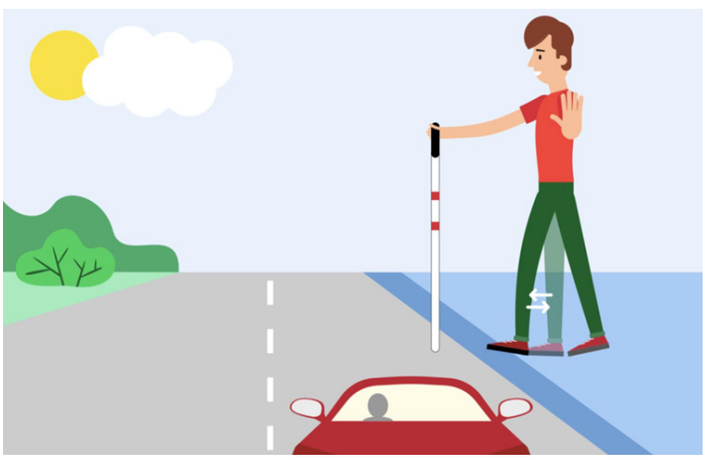


Figure 23: Advise for traffic gestures (Geleidestok - leren omgaan met taststok, n.d.)

Reimbursement for assistive products

You can get reimbursements in the Netherlands for walking aids from 'het basispakket', you do need a medical certificate for this. In the case of a guide dog, the purchase of a dog is reimbursed, some 'maintenance costs' are also reimbursed in certain situations. A blind cane is reimbursed once every three years. There is no own contribution (eigen bijdrage) but there is a deductible (eigen risico)(Ministerie van Volksgezondheid, 2016).

Laws in other countries regarding accessibility for VIPs

- In Germany people with a white cane are exempt from the "vertauengrundatz" (trust policy). They get right-of-way and are not expected to act following the regular traffic rules ('White Cane', 2025).
- n England the white cane means blind and the red bands across the cane indicate that a person is deafblind (Getting around – Deafblind UK, n.d.).
- In the USA people have to give people carrying a white cane right-of-way (National Association of Guide Dog Users, 2009).
- Argentina has passed a law that green canes indicate people with low vision, white canes are for the people that are completely blind (PERSONAS CON BAJA VISION, n.d.).

2.2.5 Key points: Market and domain analysis

Technology:

- Effective feedback can be described as having three parts; the message, the situation and the risk (Khusro et al., 2022).
- - The touch sense is the second largest informing sense in the human body making this the most probable sense to occupy for receiving additional messages (Tor Nørretranders, 2015).
- Haptic feedback seems to be the most promising type of feedback as it does not have privacy issues, environmental implications and less stigmatizing vulnerability (Khusro et al., 2022).
- AI has a lot of potential because it will keep evolving and already offers much interesting technologies such as AI vision/object detection.
- -Considering the fast growing and evolving AI tech it would be wise to keep the possibility of (future) AI integration into account.

Trends:

- Customizable and modular design offers an opportunity for the highly diverse target group as well as for making a more repairable product.
- Lightweight and durable materials would lead to a comfortably manageable and more sustainable design.
- A rise in demand for innovative and premium mobility aids is predicted making this an interesting option.

Safety and regulations:

- A training module would be wise to implement in this design, to ensure safety and the best possible experience for the user.
- The product should incorporate clear visual cues to ensure that the users are identifiable on the streets, by for instance using the white colour with red markings, reflectors or lights.
- There are specific ways to alert the environment that a person with a cane is going to cross the road, a similar function in the rollator should be considered.
- It could be that this product is subject to reimbursement under the Dutch insurance packages, the design should meet standard and remain cost-effective to ensure it could qualify for reimbursement.
- Although the current focus is on Dutch regulations, there could be thought about how this product will adapt to international standards.

2.3 Current Situation

2.3.1 Customer Journey

MVIPs face numerous obstacles daily. These obstacles are not only physical as one might initially expect, but these are also psychological barriers and the limitations of current tools. This chapter discusses these obstacles one by one.

To map out this material, several stakeholders were interviewed, and desktop and literature research was conducted. Daily challenges for MVIPs were briefly discussed in chapter 2.1 Target group.

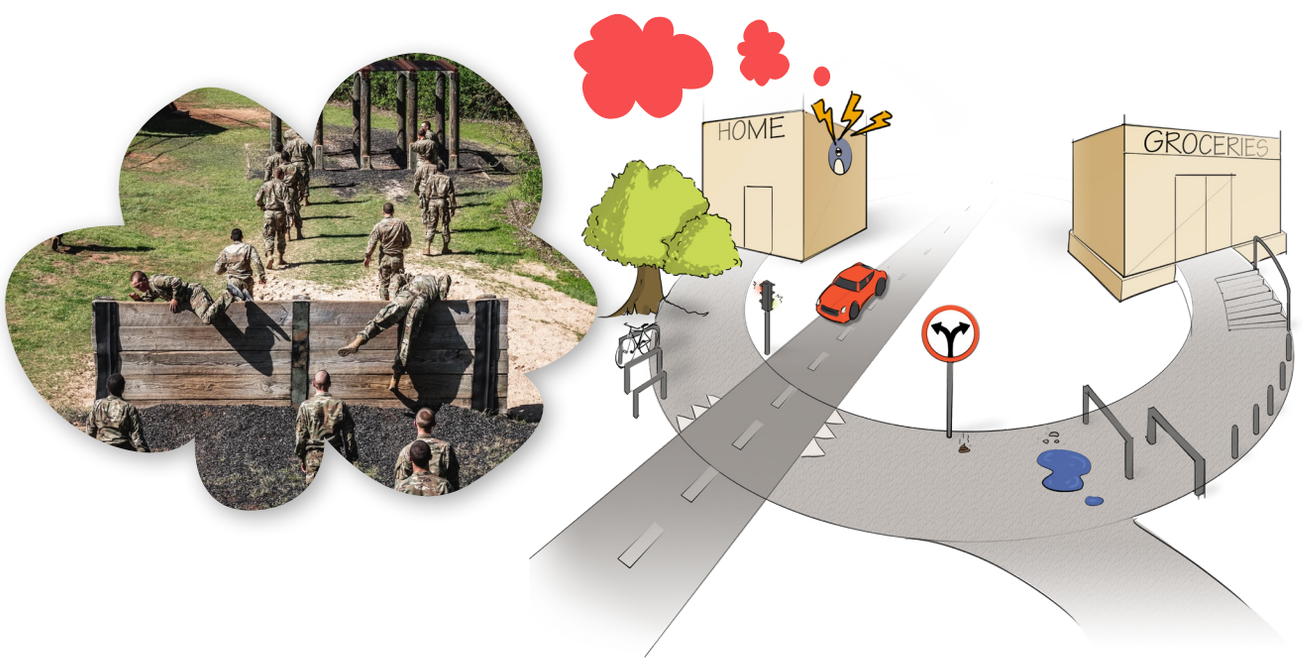


Figure 24: Customer experience

2.3.2 Limitations of current mobility tools

There are several well-known and widely used mobility aids to help VIPs and MIPs (and even some MVIPs) maintain independence and safety. However, for MVIPs these tools have their limitations that affect user experience and effectiveness. In this section, the constraints associated with mobility tools, like rollators, support canes, wheelchairs and more will be examined and discussed. There will also be looked at some of their main manufacturers. In 142Appendix D: Walking aids, a more thorough list of all mobility aids is posed.

Tools for MIPs

Rollators are commonly used to provide stability and support for individuals with mobility challenges (see Figure 25). Traditional rollators, however, often lack integrated features for obstacle detection or navigation assistance, which are important for visually impaired users. Although companies like Topro and byACRE have developed lightweight and durable models, these designs primarily focus on physical support and do not incorporate additional assistive technologies for visual impairment.

Figure 25: Rollator (Amazon.Com: Drive Medical 10257RD-1 4, n.d.)

Figure 27: Wheelchair (Medline Folding Wheelchair with Flip-Back Arms, Nederland | Ubuy, n.d.)

Support canes (see Figure 26) are designed to help maintain balance and stability, yet they do not offer the environmental feedback needed for safe navigation. Their limited range and inability to detect obstacles beyond a short distance can be a big drawback for those who require both mobility assistance and greater situational awareness.

Figure 26: Support cane (Adjustable Classic Walking Stick - Astro Group, n.d.)

Standard wheelchairs (see Figure 27) are essential for individuals with severe mobility impairments but are generally not equipped to address the navigational challenges that visually impaired users face. Operating a wheelchair independently demands accurate spatial awareness and obstacle detection, areas where conventional designs fall short. Although some wheelchairs can be modified with assistive technologies, these adaptations are not widely available and often come at an increased cost.

Tools for VIP's

Figure 28: White cane (Promoting Inclusion, n.d.)

White canes, including both identification (ID) and probe/tactile canes, are the primary aids for individuals with visual impairments. They help detect obstacles and changes in terrain, but their effective range is usually limited to about 1.5 meters, and they may not detect overhead hazards. This limitation can make navigating complex environments more challenging.

Figure 29: Guide dog (Guide Dogs, n.d.)

Guide dogs provide both navigational support and companionship, yet they require extensive training and ongoing care. Their availability is limited, and not every user may be comfortable with or suitable for working with a service animal.

Hands free tools like Orcam, Arx AI and Envision Glasses (see Figure 30) offer visual assistance, but lack the ability to convey environmental data in such a way that it can help the user navigate their surroundings without needing additional support. These products also sometimes still require operations with hands or voice commands to perform certain tasks.

Figure 30: Envision Glasses (Envision Glasses, n.d.)

There are also supporting apps like Envision that can scan environments and tell you information about it.

Tools for MVIP's

Currently a solution for MVIPs with less serious implications, general better mobility as well as better sight than the target group for this project, is a support cane for visually impaired users. This is a support cane in white with the recognisable red markings. This adaption is cosmetic and does not have any additional functionalities.

Figure 31: VIP support cane ('Adjustable Ambutech Support Cane - Classic Handle', n.d.)

There are also specialized rollators for visually impaired users that are distinguished by design features such as white frames with red stripes. However, these adaptations as well are cosmetic, and these rollators do not offer additional functionalities such as advanced obstacle detection or navigation assistance.

Figure 32: ('Rollator Topro Pegasus wit', n.d.)
Figure 33: (Rollator voor Slechtzienden, n.d.)

2.3.3 Physical obstacles

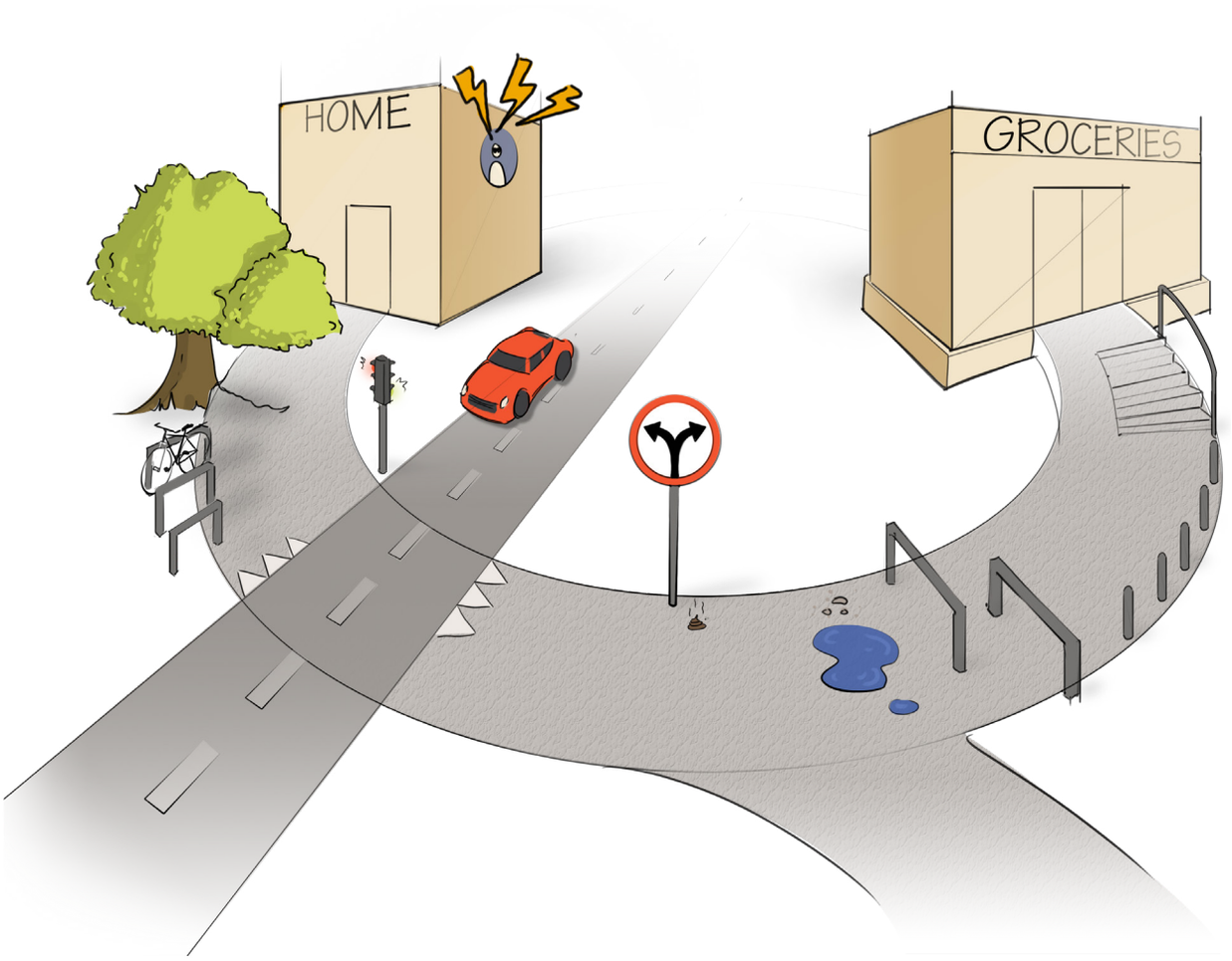


Figure 34: Visualisation of current user scenario

MVIPs need to be navigated safely past obstacles on their paths. These obstacles can be classified in different detection areas or the navigational task that will happen to safely overcome these obstacles. (Khusro et al., 2022) describe a taxonomy approach to classifying these obstacles into separate groups that represent the information that is needed to guide the user safely past the obstacle.

A list of physical obstacles was devised, although this list is not complete it conveys an image of what the obstacles are in general (see confidential appendix K).

For this project the obstacles were classified in the navigational tasks that the user will have to perform, adapted from the taxonomy described by (Khusro et al., 2022).

Actions adapted from (Khusro et al., 2022):

- Go around right
- Go around left
- Duck
- Step over
- Turn around
- Walk backwards
- Walk forwards
- Stop
- Walk down stairs
- Walk up stairs
- Walk forwards carefully/slow
- Push/open door

A few of these actions will be difficult to perform, e.g. walk up/down stairs and step over. These actions will have to be avoided with possible notifications that convey a message that says that there is an action required that cannot be performed, why and that another path must be taken.

Resulting in the list:

- Go around right
- Go around left
- Duck
- Turn around
- Walk backwards
- Walk forwards
- Stop
- Walk forwards carefully/slow
- Push/open door

2.3.4 Mental barriers

Most people do not like to be seen as a disabled person or be defined by their disability. For instance, a person stops using their cane in their town because they do not want to start conversations about this (Interview 1 with VIP, personal communication, 24 February 2025). Especially for people with later onset blindness or mobility impairment, it is difficult to accept the fact that they are losing their sight and/or mobility, and with that the ability to go about their day as usual. It can be exhausting to learn to live with visual and/or mobility impairment and learn to do things without needing the lost abilities. Losing your sight and/or mobility can be a grieving process. It is a highly emotional experience, e.g. feeling anxious, depressed, angry, confused and other negative emotions (Road et al., n.d.).

Learning to cope with sight loss is mentally tough, people have to relearn a lot of things, on the Kennis Visio website alone, under the heading of self-study, there are 21 modules to help VIPs with things in their daily life (Training en zelfstudie, n.d.).

Visually and mobility-impaired individuals often encounter psychological barriers when considering outdoor activities, such as running errands or engaging in leisure pursuits. These challenges can lead to increased isolation and reduced quality of life. Key psychological barriers include a lot of different subjects, a selection will be discussed in this chapter.

Stigma

Negative societal attitudes and misconceptions about disabilities can affect the confidence of visually and mobility-impaired individuals. Experiences of pity, overprotection, or discrimination can discourage them from engaging in public life, fearing judgment or misunderstanding. The rollators or white canes could be described as a body-near stigma-eliciting product, meaning that the product has to be close enough and in use by the user to provoke stigma (Vaes, 2014). The thesis by Vaes (2014) introduces a set of design interventions to overcome stigma in product design. These interventions were taken as inspiration to address stigma in this design project.

Aesthetics

For many individuals, including those who are blind or visually impaired, aesthetics plays a vital role in self-expression. Despite common assumptions, people who are blind often care deeply about how they present themselves ('Clothing Design for the Blind and Visually Impaired', 2015). Just like the sight-

ed population, they form a diverse group with a wide range of personal styles - from bold and fashionable to minimalist and practical.

Fashion is not solely about visual appearance; it also involves texture, shape, and pattern. These sensory elements can make clothing and accessories more identifiable and enjoyable to wear. Many people in the blind community use touch to explore and select items that resonate with their personality, favouring materials that feel good on the body and details that add character (Jasmin Ambiong, 2022).

While comfort is often prioritized, the social expectations around appearance (such as dressing appropriately for formal events) still apply. To navigate colour coordination, many blind or low-vision individuals use a combination of strategies: some rely on memory, such as remembering which colours suit their skin tone, while others ask trusted sighted friends or family to help curate outfits. In addition, tools like colour-recognition apps or tactile labels on clothing can aid in selecting and combining pieces.

Neutral tones are a common choice because they match easily with other garments, simplifying outfit selection. However, this does not mean that style is sacrificed, many express themselves through carefully chosen accessories, statement textures, or signature silhouettes.

Finally, when it comes to assistive technology, one of the persistent aesthetic concerns is the stigma of "yet another medical device." To mitigate this, designers should treat assistive products not as clinical tools, but as wearable, expressive items (just like any other piece of fashion or personal gear). A thoughtfully designed product can blend into or enhance a person's overall look, empowering users and reducing the psychological barrier to adoption.

Acceptance and mourning

The loss of vision or mobility can require significant adjustments to daily life, as familiar tasks may become more difficult or require a different approach. Individuals may need to restructure aspects of their routines to accommodate these changes, often finding new ways to perform activities they once did with ease. As these abilities decline, the need for adaptations increases, which can be accompanied by a range of emotional responses. This experience can resemble the grieving process, involving stages such as denial, anger, bargaining, depression, and, eventually, acceptance. However, not everyone goes through all these stages, nor do they always follow a linear progression. The process of adjusting to these changes is highly individual, and some may never fully come to terms with their situation (Good Mental Health, n.d.).

Dependence on assistance

The necessity of relying on others for mobility can impact self-esteem and feelings of helplessness may emerge. While assistive technologies and guide services are available, the desire for independence may make individuals hesitant to seek or accept help, further restricting their outdoor activities.

Energy and physical health

Being blind or visually impaired may cause you to have less energy during the day, for instance causing fatigue, headaches or itchy eyes. This may be because their eyes have to work harder and because they have to rely more on their other senses (Ergo Tips - Je energie in balans houden, n.d.). It could also be caused by a lack of accessible information causing a higher cognitive load in a day to understand situations and get access to information that is needed.

MIPs could experience increased physical strain during the day. Moving around takes more energy and as people want to exercise the general activities of day-to-day life, respectively more energy is needed.

For these reasons MVIPs could need more rest and less activities during the day, not only disabling them directly in their activities but also being set back in their long-term life goals, and overall development.

Social isolation

Limited access to public events and recreational activities can result in social withdrawal. The lack of inclusive environments that accommodate diverse needs often means that individuals with impairments miss out on social interactions, leading to feelings of loneliness and exclusion. MVIPs could shut themselves off from the outside world because of all the barriers to overcome by going out. Therefore, creating a downwards spiral as they lose social connections and with that, reasons to go outside. In addition to this problem, they get less stimuli which could cause their conditions to deteriorate (Interview with occupational and physiotherapists on rollator use and visual impairment in care homes, personal communication, 28 March 2025).

Anxiety

Navigating public spaces presents numerous uncertainties for individuals with visual and mobility impairments. MIPs concerns about potential hazards or encountering inaccessible environments can lead to heightened anxiety. This apprehension often discourages individuals from going outside, limiting their participation in community activities (Valangst, n.d.).

2.3.5 Key points: Current situation

Limitations of current mobility tools:

- It could be an added benefit to research the limited detection range of current aids and how this range could be expanded by using extended sensory input.
- To ensure visibility cosmetic changes could be made to the design.

Physical obstacles:

- Keep in mind that some navigational actions are difficult or not possible to perform, like walking up or down stairs.

Psychological barriers:

- Stigma is a key factor to consider when designing a rollator for MVIPs. Using the stigma design interventions proposed by Kristoff Vaes should help minimise the risk of people delaying the procurement of aids or never getting help at all.
- It is important to keep in mind that a big part of the target group is going through a mourning process during the moment of purchase or before this moment.
- Aesthetics still play a vital role in how products are perceived, VIPs tend to go for neutrals as it fits everything, but the group is still diverse and do have different fashion interests and styles just like everyone else.

2.4 Stakeholder perspectives

In this chapter the different stakeholder perspectives will be explored. Information on these stakeholders was gathered by conducting interviews, desktop research and literature review. In the following figure (Figure 35) an overview of the different stakeholder functions is made and their relation to each other is mapped. During this project, five main stakeholder groups are identified and studied, knowledge institutes, designers and manufacturers, MVIPs, healthcare providers and the government.

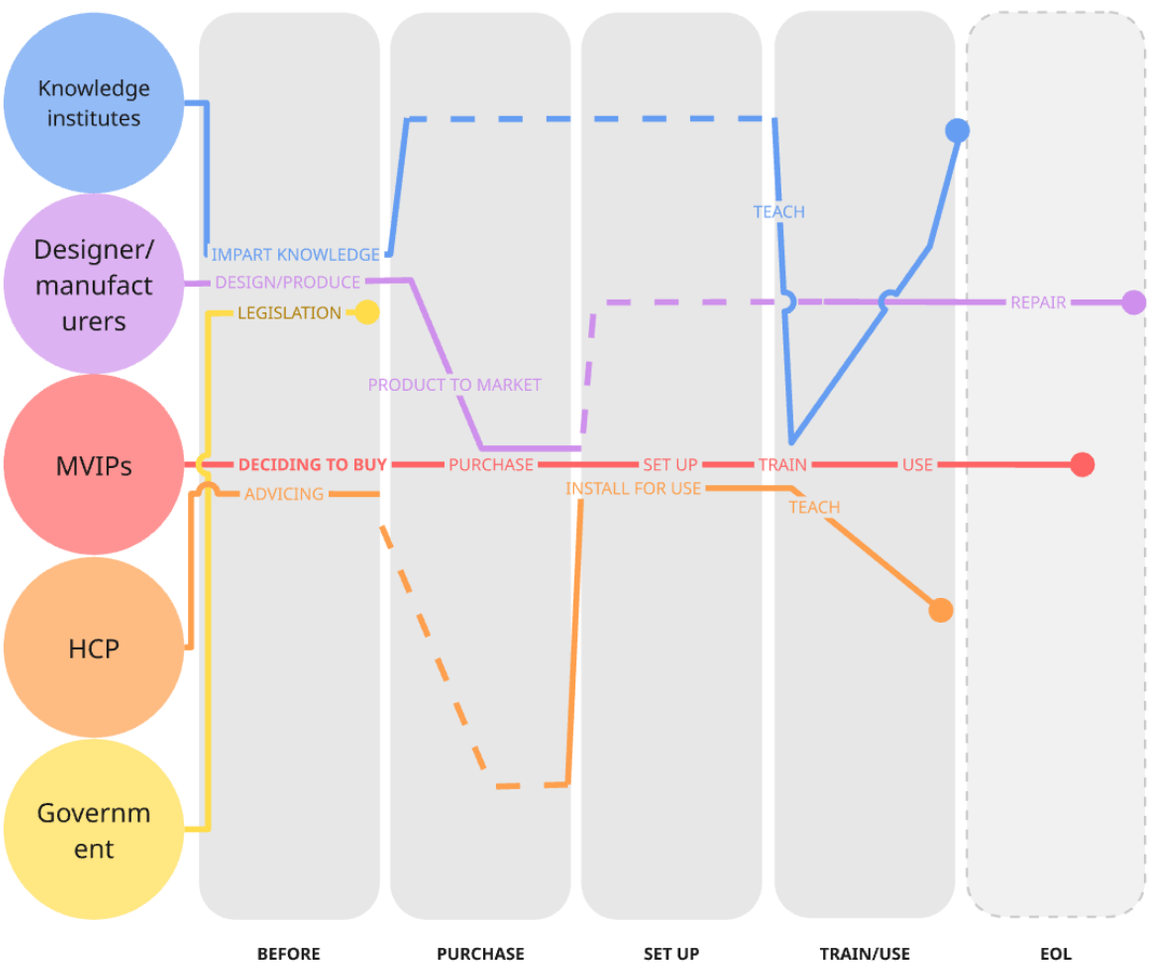


Figure 35: Overview of stakeholder relations

2.4.1 The MVIP perspective

The following section describes the main drivers for MVIPs concerning a solution for their mobility and visual impairments. Several interviews with VIPs, MVIPs and health care personnel (HCP) were conducted and from those the following needs and wishes were noted.

Expenses

This is an interesting and quite difficult topic to put real numbers with. Because this group is a diverse group of people, their budgets range from very little to a lot. There is a noticeable shift towards a higher willingness to spend more money on luxury products in the health sector (see chapter 2.2.3 Trends in mobility aid sector). Another thing to note is that this target group has a very high incentive to buy this product, as their disability is significantly limiting and the need for a solution is higher for several reasons (stimulation, independence, safety etc.).

What we can learn from the previous similar project, LEA, it was made clear that this product was too expensive and for additional reasons this project had to be cancelled.
The LEA was sold for approximately €10.000,- per unit or €237,- per month for a subscription. Compared to one of the costliest products in the rollator field ls is an electric powered rollator wheelchair hybrid called the Rollz Motion Electric sold a little under €3000,- (Rollz Motion Electric - Rollator en Elektrische Rolstoel, n.d.).

Safety

For MVIPs safety is the most limiting factor in engaging mobility related activities. If mobility and vision limitations did not pose a risk, individuals could use a rollator to support walking and move around in a similar manner to their usual routine. Unfortunately, this is not the case. The different tasks needed to move around can be classified in three different categories; static obstacles, moving people (operating vehicles) and following the route (Interview 1 with VIP, personal communication, 24 February 2025). Sighted people can see obstacles and moving people automatically, because of this there is only one of these three tasks that needs to be done consciously to move safely. For VIPs these tasks all become conscious when no additional mobility aids are used. When using a cane these tasks are done (more) automatically because of the direct feedback of obstacles and people being able to recognize VIPs. So, they know and can either move out of the way, wait or help VIPs and no longer pose as a great danger, resulting in one task that needs to be done consciously again, follow their route.

Psychological implications

This is explained in more detail in chapter 2.3.4 Mental barriers. It is important to note that MVIPs often have difficulties with mental health, this should be considered when designing a solution. A focus on going outside, stimulating the brain, reducing stigma, reducing anxiety and supporting their mental needs as they come and go.

Product aesthetics

For a lot of people their image of the outside world matters, a lot. When functionality is prioritized over aesthetics, there is a greater chance that the product will create stigma and people tend to be more reluctant in device usage. Therefore, it is important that the product should be considered "good looking" by a considerably large part of the target group. Some considerations about this could include, customizability, stylish shapes and colour options, look and feel and a fitting human to product relation. People are more likely to buy a product if they like it visually.

Comfort

The target group is looking for comfort, they are mostly elderly people. Lots of people suffer from arthritis or atherosclerosis that can get sore easily. Devices that are heavy, intrusive, not ergonomic or non-adjustable can cause physical discomfort and lead to people being less likely to use the product. Ergonomics is important for people using the product for longer periods. The use of smart materials has led to designs that are lightweight, fitting, flexible and overall comfortable for long term use (Zhang et al., 2024).

Sometimes people do not have the ability to open their hands anymore and adjustments to the rollator can be made, as for instance arm shells (Interview with occupational and physiotherapists on rollator use and visual impairment in care homes, personal communication, 28 March 2025).

Stimuli

It is often important for MVIPs to stay stimulated so that their conditions do not deteriorate any faster. When people no longer engage in daily activities due to their impairments, their brains quickly become less stimulated, which could cause their sensory conditions to deteriorate and their symptoms to worsen rapidly. On the other hand, because of their greater dependence on other senses, MVIPs will become overstimulated more quickly if these senses are agitated. So it is important to find a balance between not too few and not too many stimuli to keep the brain healthy (Interview with occupational and physiotherapists on rollator use and visual impairment in care homes, personal communication, 28 March 2025).

2.4.2 'Kennis Over Zien' authorities

Kennis Over Zien is a collaboration between the five largest bodies for the blind and visually impaired, Bartiméus, Koninklijke Visio, Robert Coppes Foundation, Oogvereniging and MaculaVereniging (Kennis Over Zien | Kennisoverzien, n.d.). Kennis Over Zien works towards a common goal of these bodies, developing and sharing knowledge about visual impairments. Through the website, but also offline, their knowledge is transferred. This stakeholder has little power over the project process but could serve as a very valuable knowledge partner. In order to be able to include this knowledge in this project, an interview was conducted with an experience expert from the Royal Visio (R. Habets, personal communication, 6 March 2025) a module on learning to deal with people with a visual impairment (Kennismaken Met Volwassenen Met Een Visuele Beperking | Kennisoverzien, n.d.) and secret information was also obtained, this can be read in Confidential appendix M.

Knowledge transfer

During these moments of knowledge transfer, some interesting things are highlighted. Such as all kinds of different tools including identification buttons, recognition canes, tactile canes, and support canes, and explain the limitations of each. Visually impaired individuals who require a rollator for stability often face significant mobility challenges. This includes difficulties with coordination, hand strength, and cognitive or hearing impairments, making independent navigation even more complex. During the interview with the expert by experience past attempts at "smart canes" with sensors but highlight issues such as high costs, weight, and usability constraints are mentioned (R. Habets, personal communication, 6 March 2025). They stress the importance of affordability and practicality, as previous smart mobility aids were often too expensive or unwieldy.

2.4.3 Healthcare Providers

The term healthcare providers (HCP) includes anyone who directly provides care to MVIPs, including ergo-/physiotherapists, care shops and informal caregivers, among others. The aim of this group is to support MVIPs and keep them as healthy as possible in the long term. To become familiar with the world of HCP and their requirements and wishes, visits were made to a care shop and a care home, and informal interviews were held with informal carers.

Efficiency

HCP often face busy schedules and full days; this makes efficiency a very important part of this process for them. This stakeholder advises, gives help with setting up and teaches users how to operate the products correctly. Interviews with these parties also revealed that currently these current processes are already very efficient, rollators are easy to understand, easy to learn and set up. It is valuable that this stays efficient.

Expenses

When a user stays in a home, rollators from the home itself are often used. If a more luxurious rollator with extra functionality is desired, it is usually purchased privately. However, homes can also buy rollators themselves, for example through organisations such as Harting Bank, with the costs being covered from the care home's budget and thus indirectly by the government. These rollators are usually selected on price and durability to last as long as possible and make efficient use of available resources. When purchasing rollators for homes, and especially for institutions for the visually impaired, it is important to consider specific needs and requirements of the homes themselves, in addition to user requirements (Interview with occupational and physiotherapists on rollator use and visual impairment in care homes, personal communication, 28 March 2025).

Advising role

The purchase path is highly personal and because of this difficult to predict. HCP should be informed about the options available as they are likely to recommend and will have to work with the product that the user will end up buying. HCP recommending a product could have a significant effect on the user purchasing pattern.

2.4.4 Government

Concerning this stakeholder, please refer to chapter 2.2.4 Safety and Regulations. This stakeholder has the least involvement with the other stakeholders but does have strong influence on the design process because of legislation and on the prices of the products as the products can either be or not be reimbursed by the government.

Legislation and product compliance

This party only has one very strong need and that is that you abide by their rules. If the rollator does not pass certification, it could be that the product is not allowed to be sold in the country of this government.

It is important to keep this in mind while designing. In the context of medical or assistive devices, this includes meeting the required product testing standards, CE marking, and possibly ISO or EN certification.

Reimbursements

As for reimbursements, this is in the Netherlands currently not a possibility. I should be checked if a mobility aid for visually and mobility impaired people could be reimbursed and taken up in the laws. This could be a very lengthy and complex process so this will be out of scope for this project.

2.4.5 Designers and manufacturers

This stakeholder group includes both design professionals and product manufacturers involved in the creation, development, and production. Their main roles vary from early concept development and prototyping to the final production, assembly, and distribution of products. Interviews and desk research were done to identify what is important to this stakeholder group.

Technical feasibility

For manufacturers, one of the key considerations is whether the envisioned concept can be realistically produced at scale. This involves practical issues such as material selection, availability of components, and the integration of electronic parts like sensors, batteries, and feedback mechanisms. Manufacturing stakeholders are more likely to support solutions that use existing manufacturing processes or components that are readily available through existing suppliers. Complexity, weight, durability, and weather resistance are common concerns, particularly in the context of outdoor mobility aids.

Production costs

The cost of production is a central factor in whether a concept can be brought to market. If a design includes custom-made parts or niche technologies, it may result in high production costs, which in turn affect the retail price and affordability for users. For this reason, manufacturers tend to favour modular designs that can be adapted or scaled across different product lines, and designs that reduce the number of unique parts. This can help lower tooling and assembly costs and create the possibility of shared parts between products.

Brand alignment and perception

Designers and manufacturers are also concerned with how a new assistive product aligns with the brand identity and existing product portfolio. If a product visibly differs from others in form language, material finish, or colour palette, it may be seen as inconsistent. On the other hand, well-aligned products can strengthen the company's image and support communication strategies that highlight innovation, inclusivity, or sustainability. For companies operating in the healthcare or mobility aid market, aesthetics also plays a role in how products are perceived by end-users and professionals.

Development resources

The availability of in-house expertise, prototyping tools, production facilities, and external partners can influence whether a manufacturer is able or willing to participate in the development of an assistive technology product. Smaller manufacturers may not have access to the same resources as larger companies and may require additional support in areas such as electronics integration, app development, or testing with user groups.

2.4.6 Key points: Stakeholder perspectives

Expenses:

- The budget for this product can vary widely, there is an opportunity here to make several different options for the different budgets people have.
- A subscription to the product could offer an interesting way to test the product for the user, to be able to edit a product package as the solution will most likely be modular and to make the threshold to start using this product less high.

Safety:

- It is important that the to be designed product ensures this safety as well, at least at the level that a cane or a dog can ensure safety.

Aesthetics:

- Involving the target group in the design process could lead to products that are both effective and aesthetically pleasing.

Touch sense:

- During the interview with the occupational- and physiotherapists it became evident that the touch sense was for elderly people with multiple disabilities, one of the senses that worked best for the longest while other senses start to deteriorate over time. This could be a reason to choose this sense as the main sense to present the feedback to.

HCP:

- It is important that the moments that the new products stays at a comparable level of complexity in comparison to the currently used rollators and/or white canes.

2.5 Conclusion analysis and immersion

Based on this analysis, the problem statement was revised to the following statement:

'MVIPs (just like anyone else) need to independently stay active and go outside and get stimulated, to maintain physical and mental health. Safety and stigma issues are preventing this today.'

With this new problem statement the project objectives were also reimagined:

'To design an integrated assistive solution that merges the environmental awareness provided by tools like a white cane or guide dog with the physical support of a mobility aid, empowering individuals with combined mobility and visual impairments (MVIPs) to move through their environment more safely and independently.'

The overarching aim is to develop a product-service keeping the pillars shown in Figure 36 in mind.

Figure 36: Project objectives based on analysis

CHAPTER 3

Synthesis & conceptualization

3.1 CONCEPT DIRECTIONS | 85
3.1.1 APP BASED MODULARITY | 85
3.1.2 MODULAR PACKAGES | 85
3.1.3 WEARABLES FOR ALL | 85

3.2 FINAL CONCEPT DIRECTION | 87
3.2.1 DESIGN CRITERIA | 87
3.2.2 CONCEPT DIRECTION SCORES | 87
3.2.3 SELECTION | 87

3.3 CONCEPTUALIZATION | 89

3.0 Synthesis & Conceptualization

For a product service system to deliver on the objectives put forward in the previous chapter, a few different perspectives can be taken to shine light on the design task. For this, three different design directions are described and measured on their desirability, feasibility and viability. Once the choice was made for what direction to go with the design, an overview of the different subject components was needed to get the ball rolling. Using a morphological map, this chapter weighs these components against each other and synthesises an outcome of a final concept that can be elaborated on and embodied in the next phase.

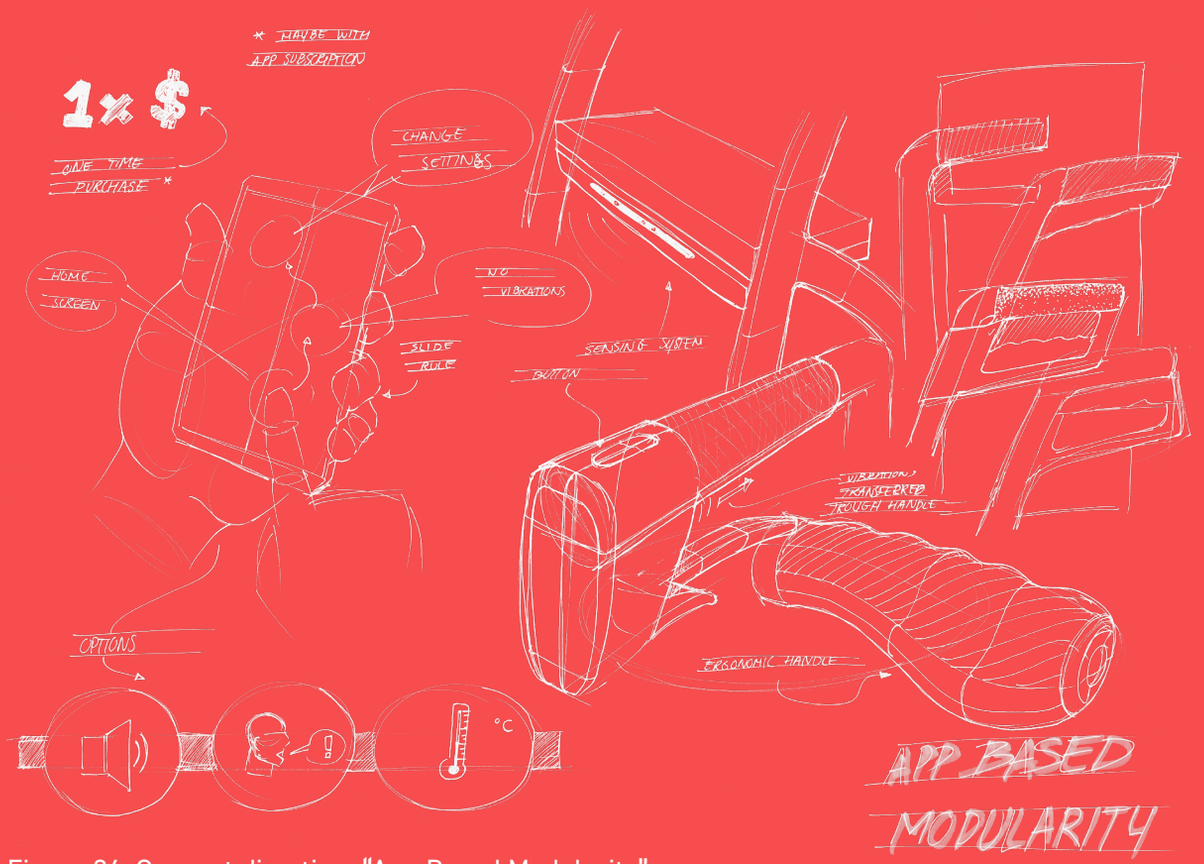


Figure 36: Concept direction "App Based Modularity"

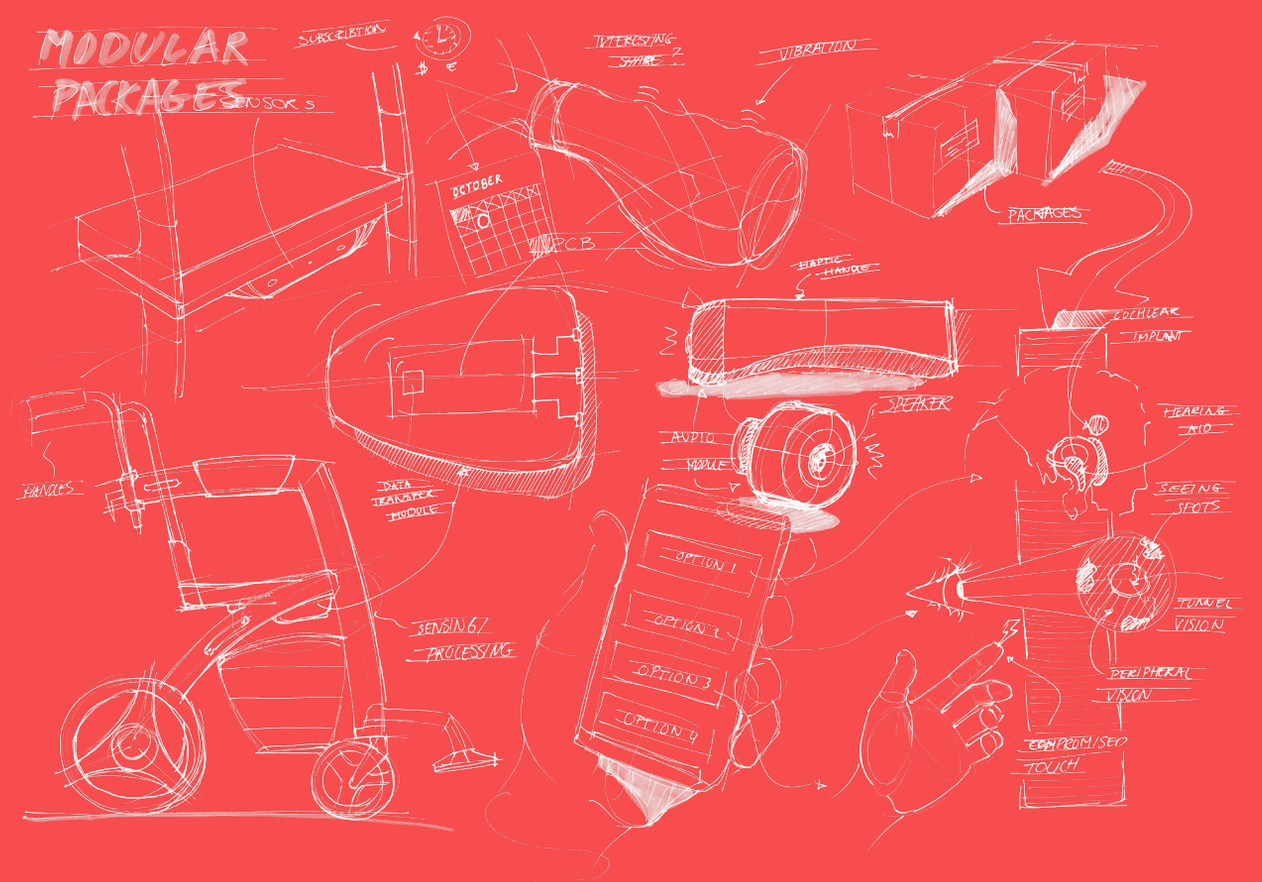


Figure 37: Concept direction "Modular Packages"

3.1 Concept directions

Taking into consideration the existing products, the previous research conducted and the hands-on experience of working with a company that creates rollator product services for real life scenarios: three different design approaches are put forward that can be used to look at the problem statement, the scope and the objectives.

3.1.1 App Based Modularity

The first concept is based on modular design via an app. The specific feedback and settings can be changes in the app and because of the focus on the customization, this feedback will be integrated into the seat and handles of the rollator. Using the app the user can change the type of feedback and other settings to their personal preference.

3.1.2 Modular Packages

The second concept has a more physical approach to achieve modularity and customization. The design works with modular packages that give the ability to customize products around the personal needs of the users. This concept would be a monthly subscription where the user can start with a basic package and built on that further, the products will grow with the user's wants and needs. This will be a more service-based concept direction and has different points to grow on than the other directions. It for example could recommend certain packages based on user data using an algorithm.

3.1.3 Wearables for all

Thirdly, a concept is proposed where a wearable for more universal purposes is designed. A reactive wearable together with a sensing module - that will not necessarily be tied to a rollator -, can be intuitively used by users other than MVIPs needing a rollator. It will be a modular design that is not integrated in a walking aid and can be suitable for other walking aids. Using the feedback, this wearable will have an app that can customize the user experience and specific aid needed.

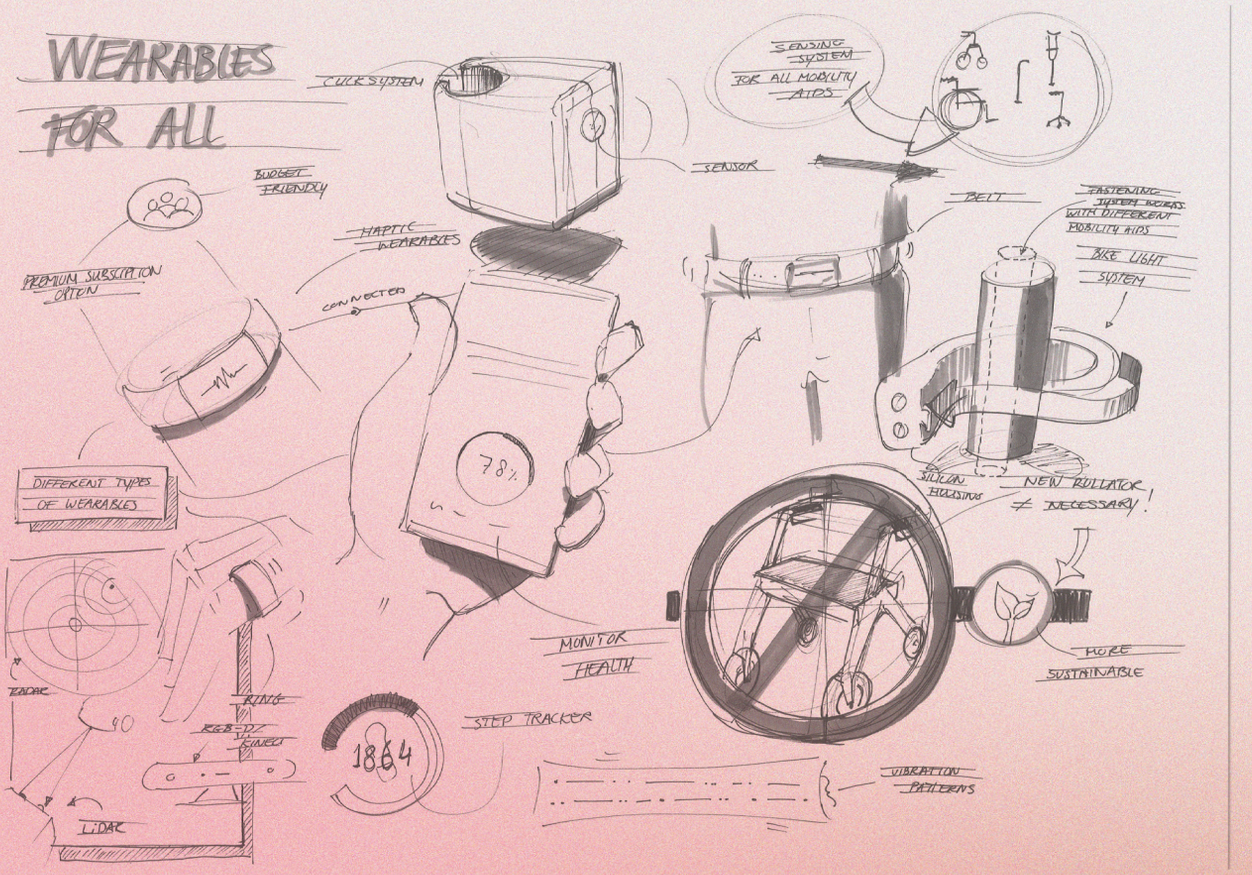


Figure 38: Concept direction “Wearables for all”

3.2 Final concept direction

3.2.1 Design criteria

The three concept directions were assessed on the following criteria .

- Desirability
  - Value / need
  - Ease of use
  - Aesthetics
- Feasibility
  - Complexity
  - Technological availability
  - Time Horizon
- Viability
  - Risk
  - Cost effectiveness
  - Market potential

These criteria are based on the key pillars for Industrial Design Engineering at the TU Delft.

3.2.2 Concept direction scores

Based on these criteria, a radar graph (see Figure 39) was made showing the scores for all three concept directions.

3.2.3 Selection

Seeing this graph (Figure 39), it can be concluded that "Wearables for All" is the most promising of the concept directions. It scores highest in the most criteria. It for example has a higher expectancy for being cost effective, since the overall product can be more generalized than custom parts for a stroller. It would also have a higher market potential, because it would reach a larger target group.

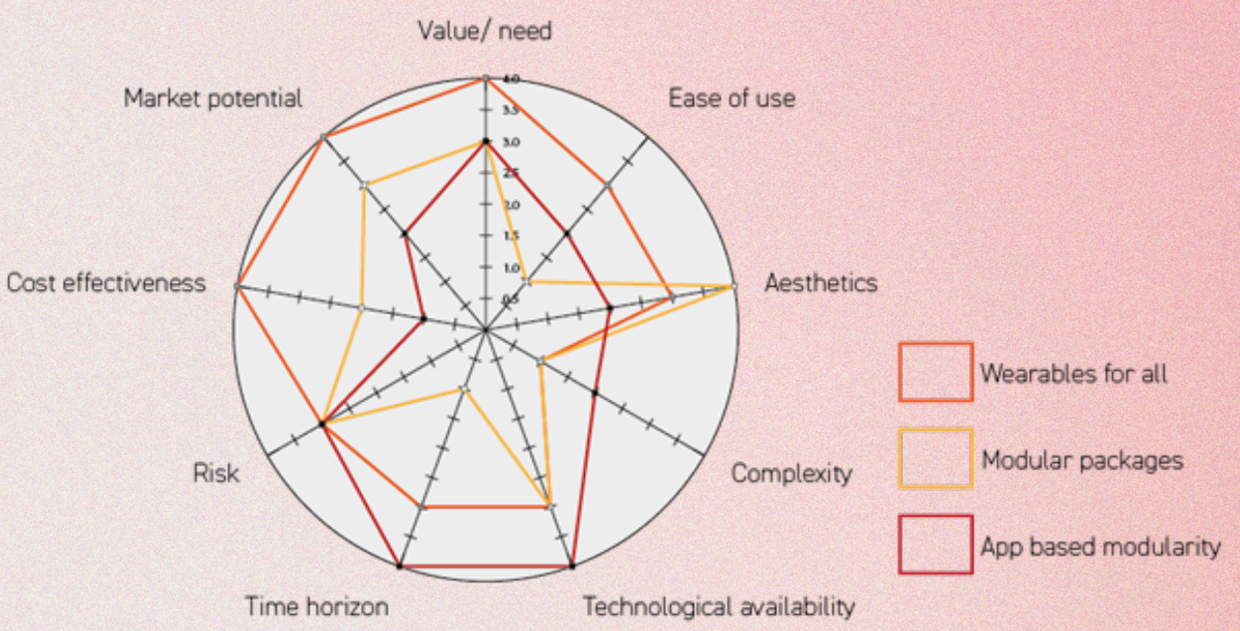


Figure 39: Scoring of concept directions based on chosen criteria

3.3 Conceptualization

An overview of factors that fit in the 'Wearables for All' design direction consists of:

- Purchase
- Sensing technique
- Sensing placement
- App
- Processing location
- Processing technique
- Feedback type
- Training
- End of life

The different components that make up this concept direction are elaborated on in this chart. For all components a couple perspectives are taken to how it could be realised and the options for these components are assessed to eventually come to a combination of options that would make the most optimal design concept. To make this clearer a morphological chart was made to identify different options and try out different combinations. This chart can be found in Appendix E: Morphological chart.

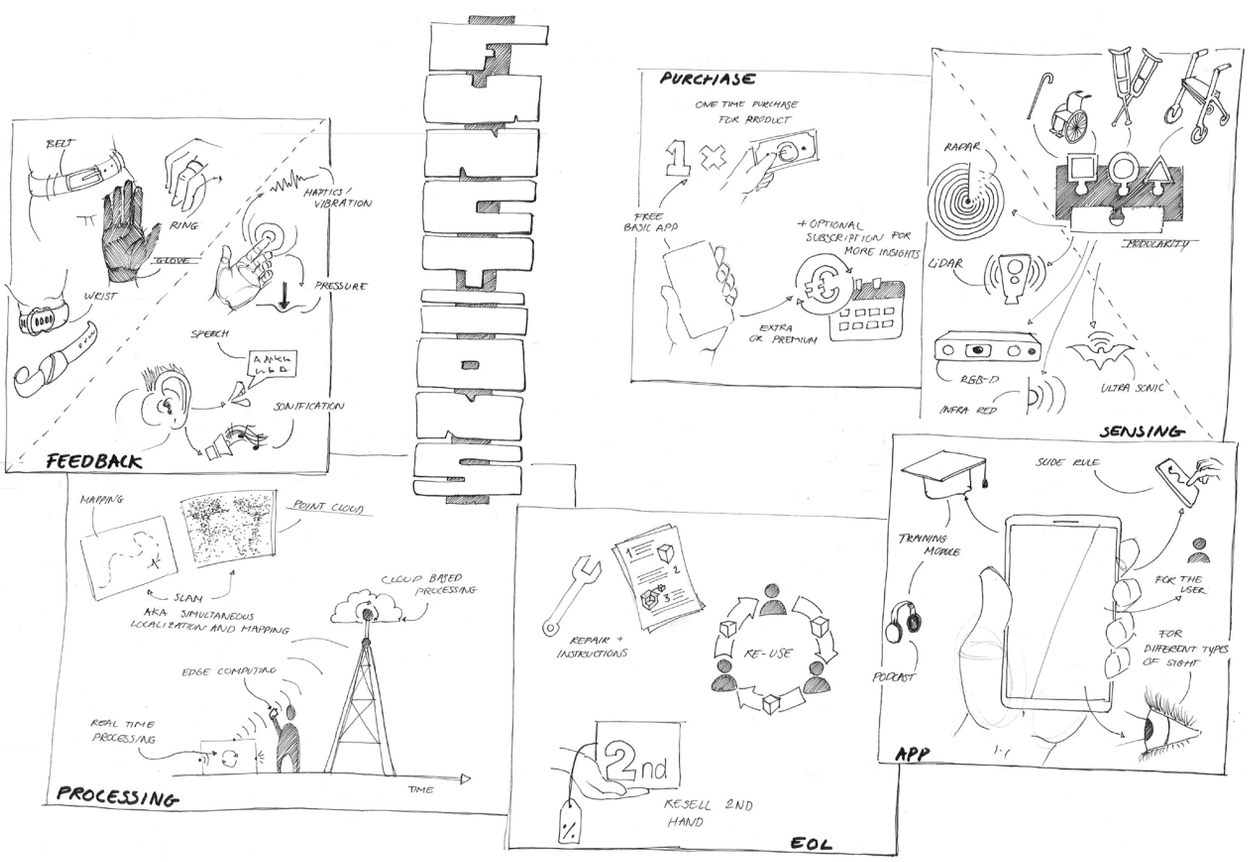


Figure 40: Overview of different functions of the chosen concept direction

CHAPTER 4

Elaboration & embodiment

4.1 ASSIGNMENT ELABORATION | 95
4.1.1 SCOPE ITERATION | 95
4.1.2 USER ELABORATION | 95
4.2 SYSTEM OVERVIEW | 96
4.2.1 WHAT THE DESIGN OFFERS THE USER | 97
4.2.2 BRAND IDENTITY |100
4.2.3 CUSTOMER CUSTOMIZATION |102
4.2.4 RECOGNIZABILITY IN PUBLIC SPACE |102
4.3 DIGITAL EMBODIMENT |103
4.3.1 VAMO APP |103
4.4 PHYSICAL EMBODIMENT |107
4.4.1 VAMO WEARABLES |107
4.4.2 VAMO SENSING MODULE |111
4.5 FINAL DESIGN |120
4.5.1 OVERVIEW |120
4.5.2 KEY FEATURES AND USER BENEFITS |121
4.5.3 USER SCENARIOS |122
4.5.4 RULES AND CERTIFICATIONS |124
4.5.5 COST ESTIMATION |125

4.0 Elaboration & embodiment

Following the general structure of the Double Diamond design approach (as mentioned in chapter 1.4 Project approach), further elaboration is needed to converge after selecting the concept, in order to refine and narrow it down to a final design proposal. This is done by iterating the goals and the scope to better specify them in accordance with the new concept direction. The specific context and users are also elaborated on. After this, the embodiment of the design concept in question will be manifested. Firstly, by looking at what kind of a system will lay the foundation for this product. Secondly, the chosen product will need a digital foundation. Looking at the functions, the graphic design and readability of the app. Subsequently, the physical components are embodied, starting with the wearables and then the sensing module. For these two parts, the functions are defined, the internal specifications are defined and are tested where necessary. For the fastening system, different options are also considered and abstracted. Finally, the chapter is concluded with an overview of the final design, looking at sustainability, lifecycle, user experience, cost, rules and certifications and ending with recommendations for future projects.

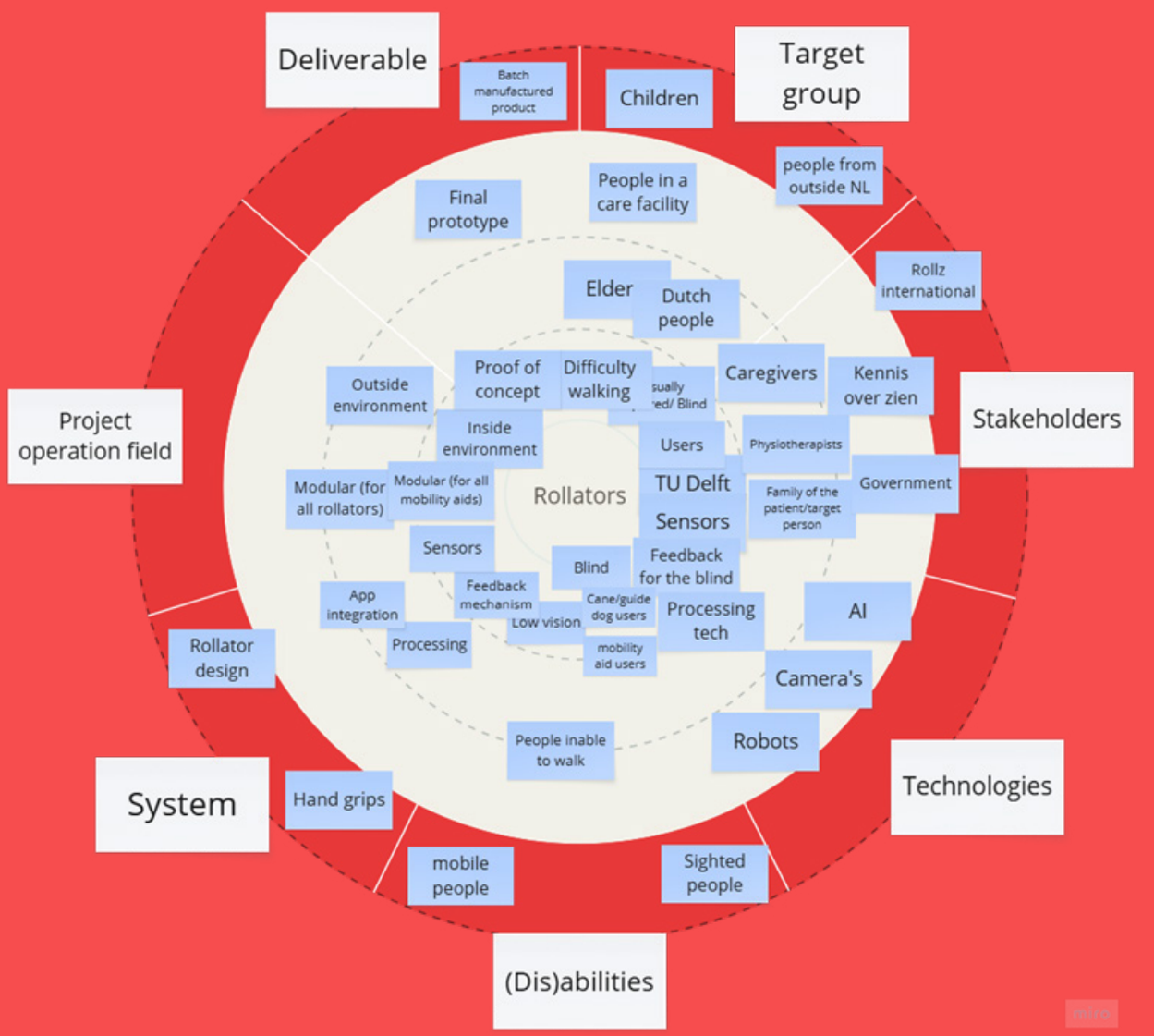


Figure 42: New scope

4.1 Assignment elaboration

4.1.1 Scope iteration

Beginning this elaboration phase, the scope was adjusted to not only include rollators anymore. The goal was set to instead look at all available mobility aids that require the use of both hands and use them to make the system even more universal. In Figure 42 the new scope is visualised.

4.1.2 User elaboration

With this change in scope and goals comes a change in target group. A short study was conducted to map what types of mobility aids exist on the market. This was done to elaborate on what kind of users and subsequently what types of mobility aids the wearable must fit with. This research can be found in Appendix D: Walking aids.

What is important to note from this research is the physical constraints this leaves to where the sensing module will have to mount to. Although this is mainly round tubes a few stand outs were observed where the tube is not round but more elongated or with oval shaped sections.

4.2 System overview

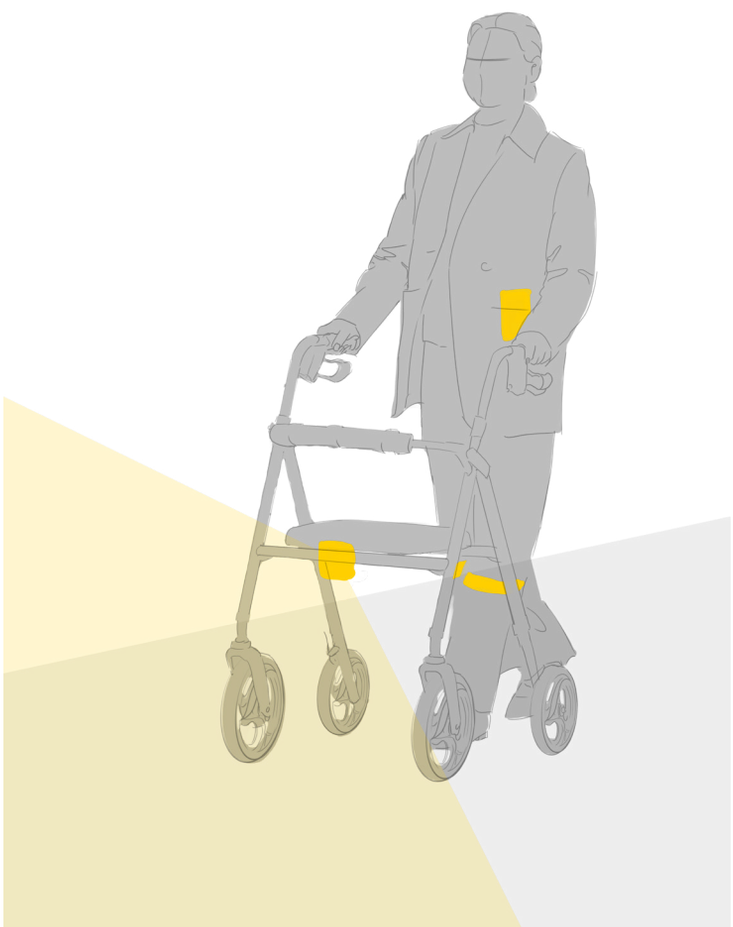


Figure 43: Design systems

The system for the 'Wearables for All' design uses components in three different zones. These zones are the wearable, the sensing unit and the app. Those design components are shown in Figure 43 and in Figure 45.

Connection is made between the three different subsystems to integrate this product into an efficient product-service design concept. Because those three components are not dependent on the mobility aids that they are used on, it is called a modular system. With the wearable providing vibrational feedback and the app providing auditory feedback, it makes mobility for MVIPs more accessible. The sensing and detecting components in the sensing module are used to increase the safety of this guidance. Finally, the app allows for the user to interact with the whole system and improve the use of the physical and digital embodiment of the design.

4.2.1 What the design offers the user

To enhance the life of MVIPs, VAMO was designed. Through a modular, user-centred setup, the system supports the diverse target group, promoting greater independence, safety and self-confidence. The system works by complementing the user's existing abilities, rather than replacing them and by this supporting their autonomy. For example, the users who still have partial vision can rely on their remaining sight while receiving subtle assistance in the areas they cannot perceive, such as obstacles outside their visual field. Those with more severe impairments can choose from a broader subset of support options, including auditory cues.

Key features include:

- Obstacle and route feedback via customized vibration patterns
- Personalized user interface (UI) settings such as font size, contrast and colour schemes
- Text-to-speech and optional audio guidance for additional orientation
- Adjustable feedback intensity and modality, to ensure that the user can fine-tune the system to match their needs and preferences.

Users can fully customize these features via the accessible VAMO app, allowing them to adapt the product to their daily needs, physical condition and environment. The design promotes independence, autonomy and aesthetic appeal, empowering MVIPs mentally and physically.

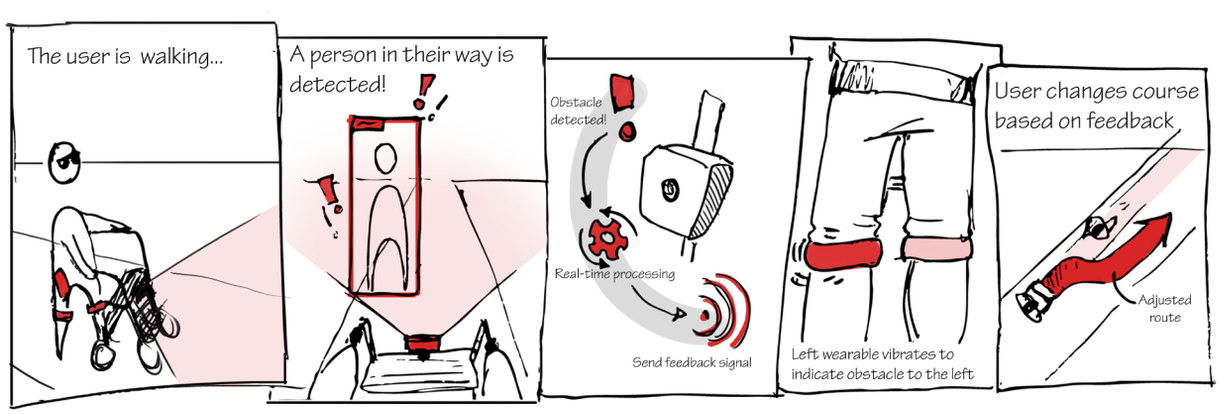


Figure 44: Story board basic use of VAMO

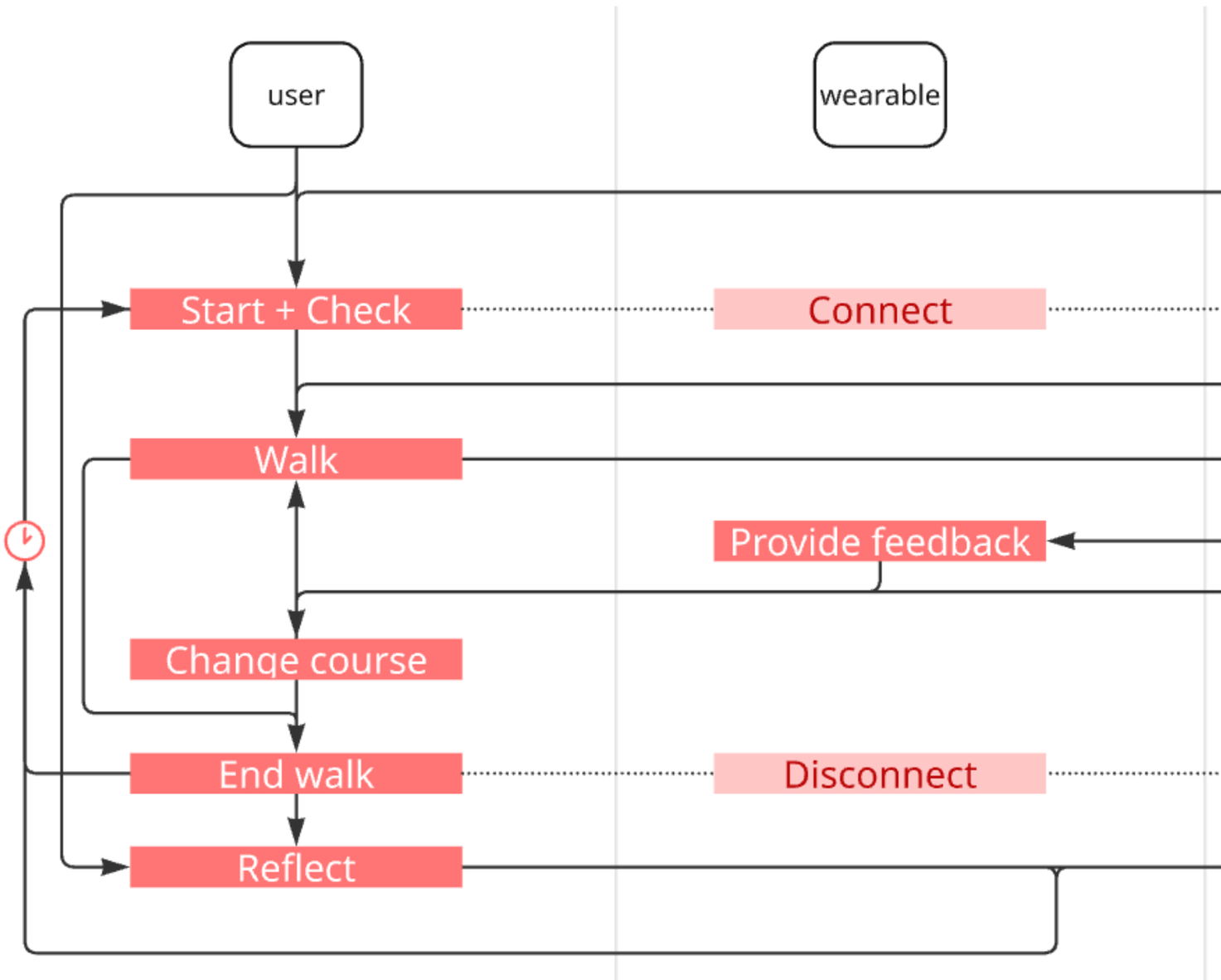
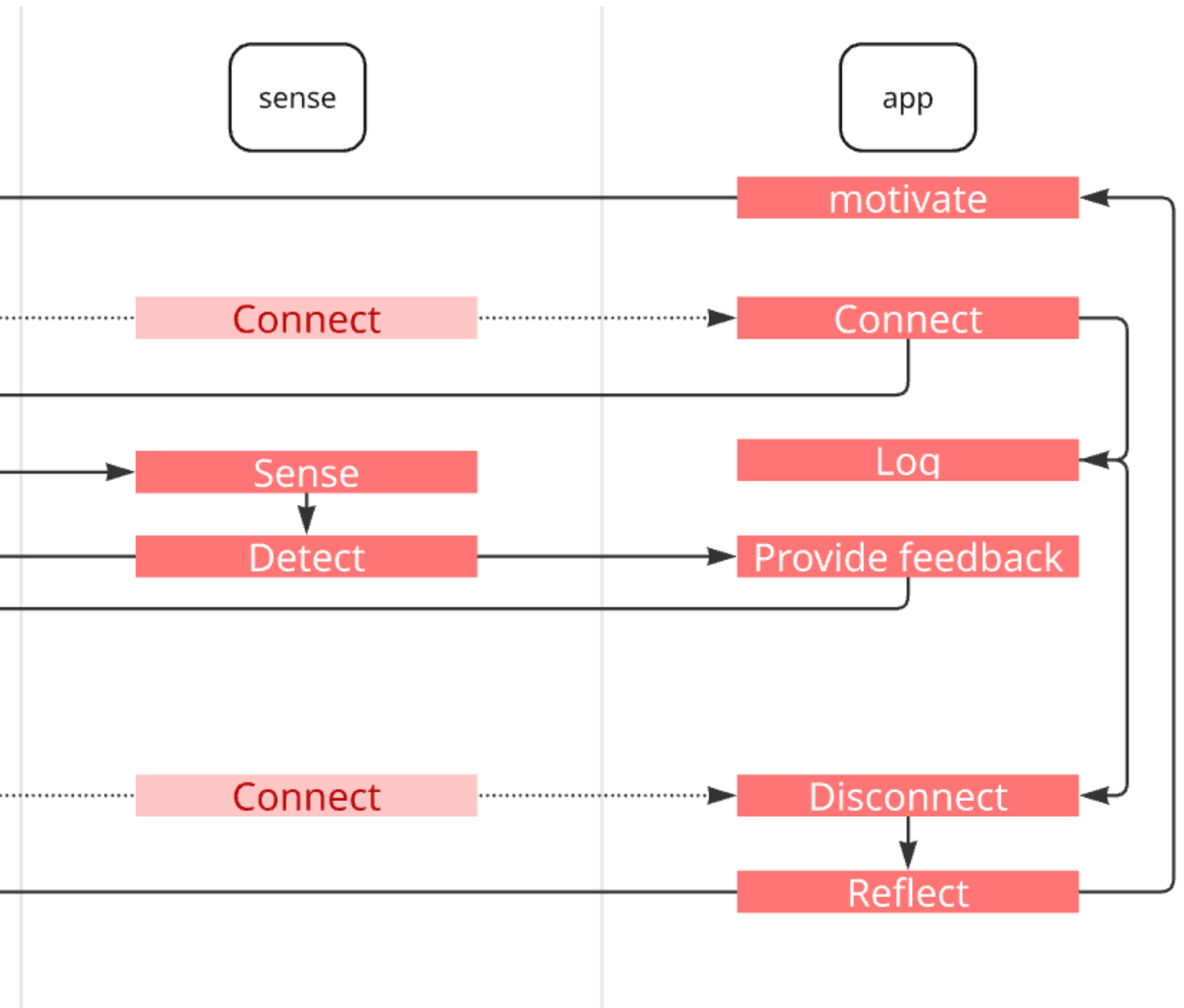
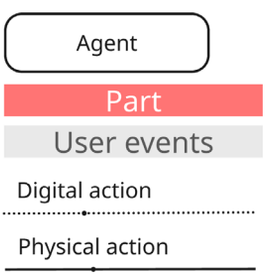


Figure 45: System function overview


sense
app
motivate
Connect
Connect
Sense
Log
Detect
Provide feedback
Connect
Disconnect
Reflect


Agent
Part
User events
Digital action
Physical action

4.2.2 Brand identity

The product-service system designed in this thesis is called VAMO. Which is an abbreviation for Visual Assistance and Movement. This brand name was chosen because of its simple pronunciation and resemblance to the Spanish word "vamos" which means "Let's go". To establish this brand identity several words connected to values were chosen based on the project objectives and other key takeaways from 2. Analysis & immersion.

These words are;

- Healthy
- User autonomy
- Customizable
- Helpful
- Smart
- Friendly
- Technological
- Safe
- Independence
- Trustworthy

In Figure 46 a part of the process of defining the logo is shown. The icon in the logo, visible in Figure 48, represents a vibration pattern and resembles the front view of the sensing module.

Figure 46: Logo sketching

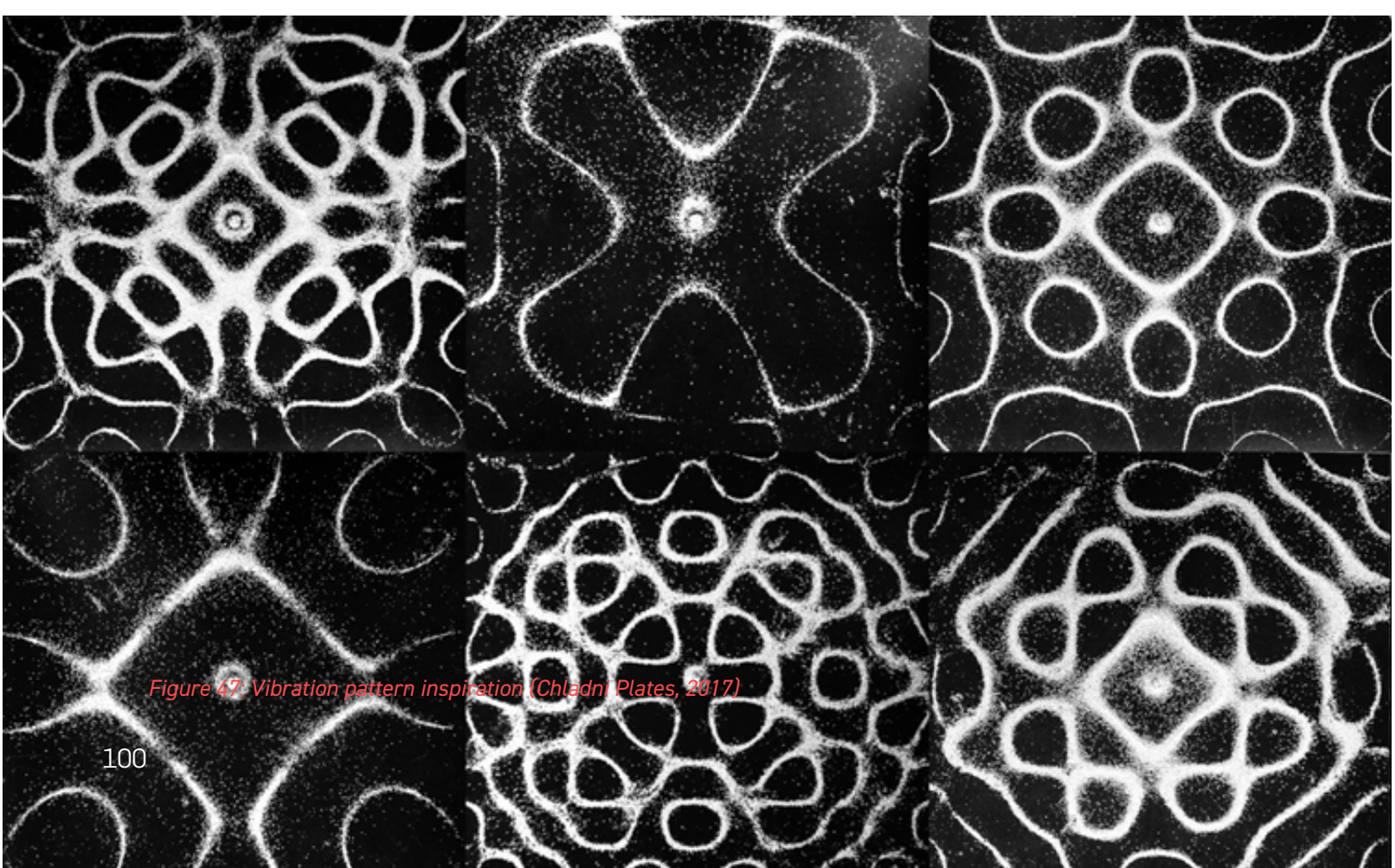


Figure 47: Vibration pattern inspiration (Chladni Plates, 2017)

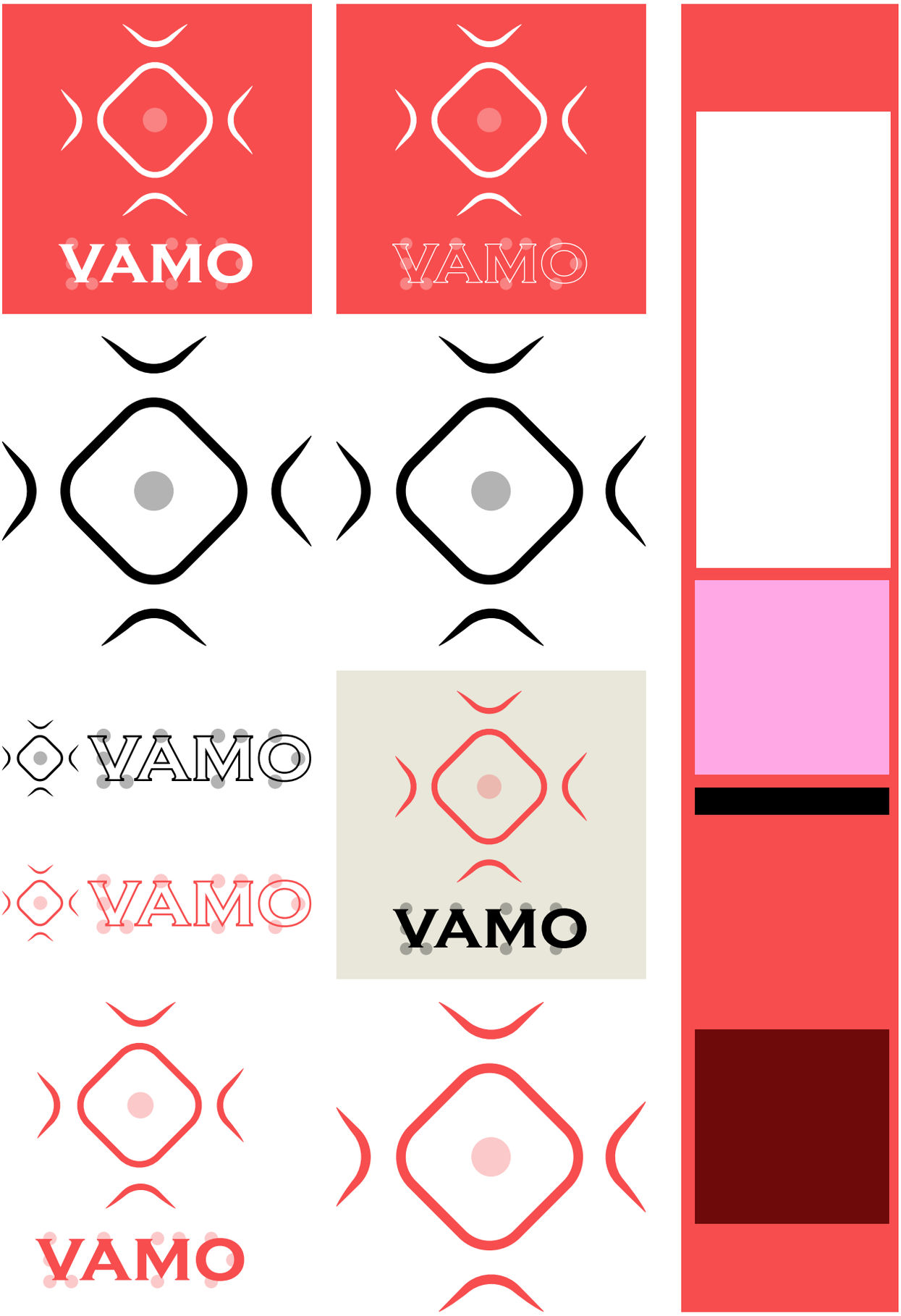


Figure 48: Branding

4.2.3 Customer customization

One of the key takeaways from the research phase is the importance of customization to support user independence. Since the target group includes people with a wide range of visual and mobility impairments, their needs and preferences vary greatly. Customization allows users to tailor the system to their specific abilities and daily routines, reinforcing their sense of autonomy rather than imposing a one-size-fits-all solution.

By offering flexible settings, the system supports different levels of assistance. For example, a person with tunnel vision may still rely on their remaining sight for navigation and only need targeted support for obstacles outside their field of view.

To accommodate such differences, users can adapt the interface and feedback mechanisms to suit their individual preferences. These customization options (further detailed in chapter 4.3.1 VAMO app) include adjusting font size, contrast, and colour schemes, enabling text-to-speech, and modifying feedback settings such as vibration intensity, vibration patterns, and optional audio cues. All these settings can be configured through the VAMO app.

In chapter 4.5 Final design different scenario based on three personas are explored to see the different outcomes that can be achieved with this system.

4.2.4 Recognizability in public space

For MVIPs, especially those who are fully blind, being recognizable in public as a VIP is often essential for safety (see chapter 2.2.4 Safety and Regulations). This is why many visual aids use standardized visual markers such as white and red colour schemes. While the VAMO system may include these visual cues (when chosen for), its compact size may limit visibility on its own. It is therefore important that users consider how they present themselves in public space.

The system respects that not all users may wish to be visibly marked, especially those in earlier stages of vision loss or those concerned about stigma. VAMO wants to prevent the product not being used because of these concerns. As such, VAMO supports both visible and discreet use through colour options. Guidance on making these decisions is provided through the in-app coach, which helps users weigh visibility and personal preference in a safe and informed way (see chapter 4.3.1: Coach function).

4.3 Digital embodiment

This section will be used to describe the digital embodiment of the design concept. The goal of this section is to clearly define what the digital part of the project consists of.

4.3.1 VAMO app

Figure 49: App UI mock-up

The first part of the design is the app. This app is the UI of the project. The way for the user to communicate with the whole system is via this app. The design of the app stayed very simplistic to not distract the user or overstimulate them.

App functions

Firstly, defining the functions this digital part of the project must perform. In the flowchart the app is pulled apart from the physical system and the relations it has with the user and the parts of the wearable and the sensing module. The app will use Bluetooth to connect with the physical system and receive feedback through this connection to send the impulse to the phone speaker, which in turn will make clear to the user what is happening.

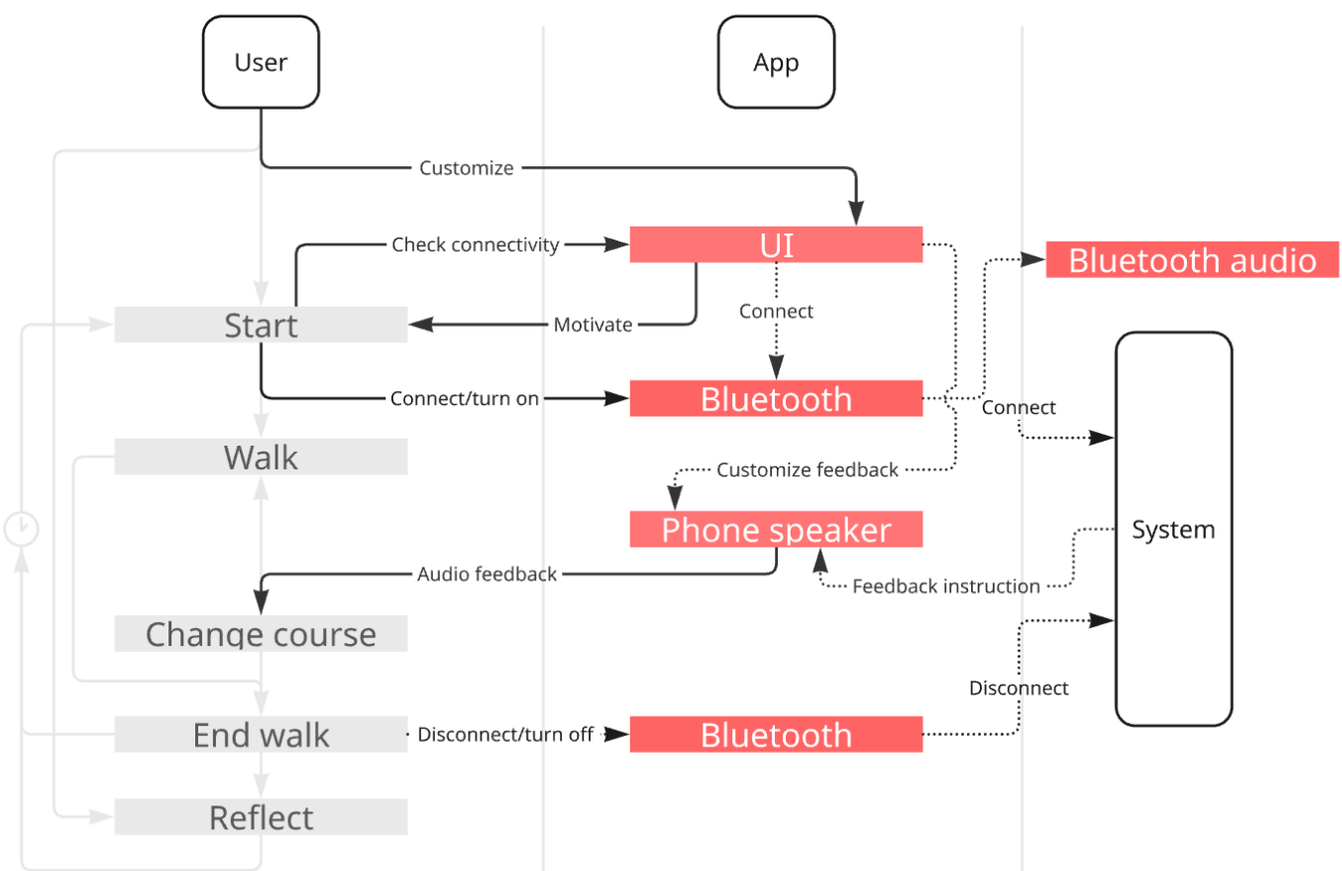


Figure 50: App function overview

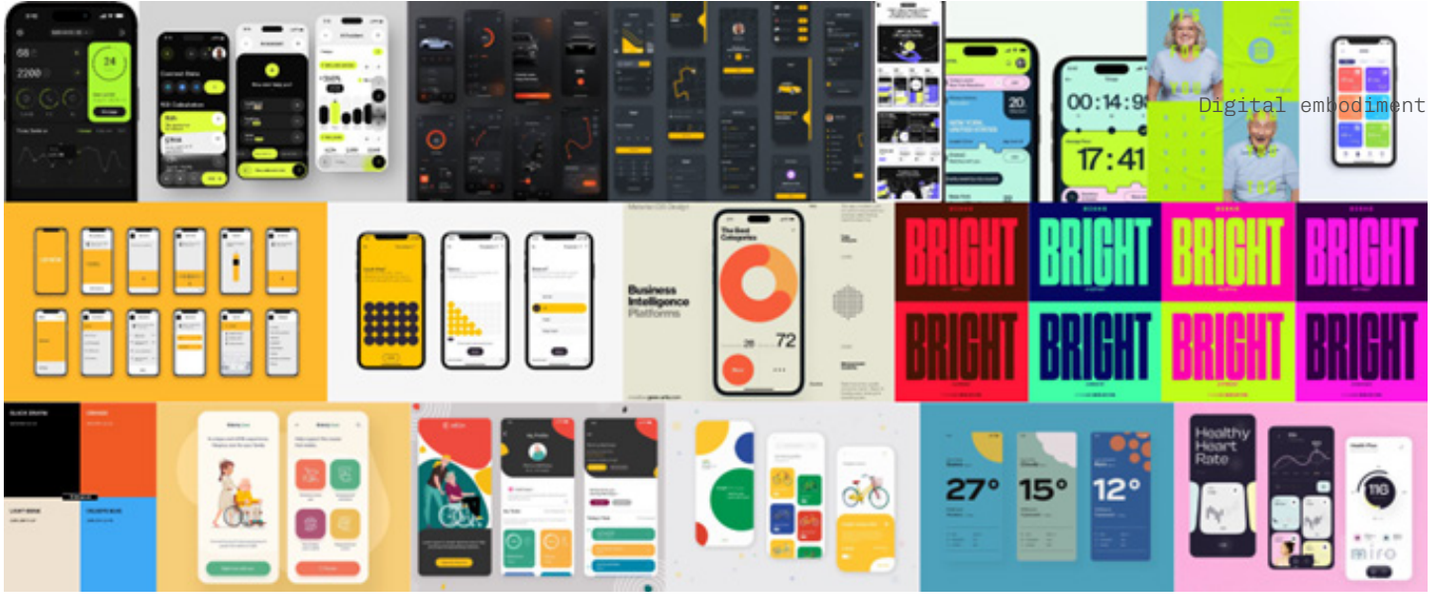


Figure 51: UI mood board

Graphic design

For the graphic design of the app a style is used that is bold, contrasting and very clear. In the mood board below, it is visible what is meant with this. While not all users from the target group can see the app, for some that have a partial eyesight, this is of the highest importance.

Without the contrasting and bright colours, the user experience would be less accessible. Nevertheless, as mentioned before, the target group is diverse, so diverse that different contrasts could be preferred for different people, so there will also be an option to edit this.

Figure 52: Example text sizes and fonts (Choosing a Font for Print | Plum Grove, n.d.)

Readability

For the same reasons that the contrast needs to be high and customizable, the size of the text and of the app will also be adjustable. In Figure 52 it can be seen how different sizes of text and types of fonts can be easily adjusted and will improve the readability of the app.

Customization

One of the findings from the analysis phase was that the users want to be able to do the things that they are still able to do. For instance, someone who has tunnel vision still wants to use that information that they can see to move independently and only be assisted in the things that they cannot see. To accommodate this whish, the user can customize the system to their own wants and needs. They will be able to change font size, contrast, colour schemes and other UI options like text-to-speech, next to that they can also change the feedback settings. These settings would be the vibration intensity, type of vibrations (patterns) and turn on/off optional audio, all from within the app.

QUOTE

"Someone would need a good cursus, before going outside with the vibration"

~ Research participant

Coach function

The coach function is a central component of the VAMO app, designed to guide users through learning how to use the product safely and confidently. Acting as a digital tutor, the coach introduces users to VAMO's functionalities through clear, accessible formats (such as a podcast) and supports gradual onboarding at the user's own pace.

Beyond functionality, the coach also educates users about the implications of using the product in public space. For individuals who are fully blind, it is crucial to remain visibly recognizable to others, for instance, through the internationally recognized white and red colour cues often used in white canes. While VAMO may be available in these colours, its compact size means it may not always offer sufficient visibility alone. The coach will therefore guide users in making informed decisions about how to ensure their visibility, whether by choosing appropriate accessories, adapting their primary walking aid, or wearing additional identifiers as a visibility button. At the same time, the coach respects user's personal preferences and acknowledges the stigma some may feel around visible markers of disability. For those in earlier stages of vision loss or who prefer more discretion, the system supports more subtle use. Ultimately, the goal is that as VAMO evolves and technology becomes more seamless, users may one day navigate the world independently without needing to be identified as blind at all. Until then, the coach helps users balance safety, autonomy, and self-expression.

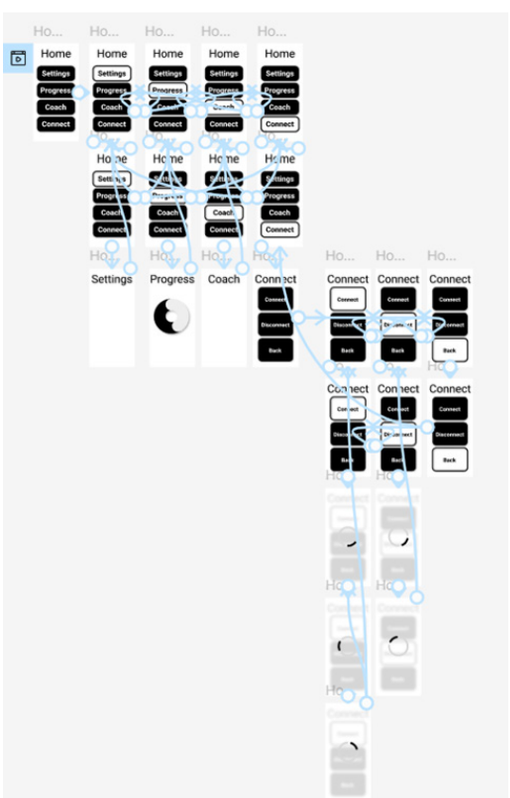


Figure 53: Figma prototype wireframes

App prototype

As part of getting proof of concept for VAMO, an app prototype was developed using Figma to explore the digital interface and user interaction. Designing an app for people with little or no vision presents unique challenges, as conventional visual elements and navigation patterns may not be accessible. This made the prototype development especially interesting, as it required focusing on alternative interaction methods such as haptic feedback, audio cues, and simplified layouts that prioritize ease of use without relying on sight. The prototype allowed early testing of these ideas and helped clarify how the app could complement the wearable device, providing intuitive feedback and control options tailored to the needs of users with combined mobility and visual impairments. This user-centred approach ensured that accessibility and inclusivity remained at the core of the digital design.

4.4 Physical embodiment

The following section will describe the elaboration of the physical design. The goal of this section is to bring the physical design to life, decide on the details and specifications and to prototype the design in a way to confirm if it can work.

First of all, it is important to keep in mind the functions that this physical design needs to perform. To keep a good overview of this, a differentiation is made between the wearables and the sensing module.

4.4.1 VAMO wearables

Figure 54: Wearables (fastening not modelled)

The wearables of this system are designed to provide the user with intuitive feedback. They play an important role in translating the environmental information (obtained by the sensing module) into accessible haptic cues. Beyond its technical function, the wearable also addresses key human-centred design factors: it is customizable, modular and ergonomic, reducing stigma through thoughtful aesthetics and placement and offering comfort across different body types.

QUOTE

"[I] think the vibrations on the knees are perfect because your legs are the tools that need to walk!"

~ Research participant

Wearables functions

To gain a clear overview of the functions that the wearables should perform a function chart was made in Figure 55. In this figure it becomes clear what the interactions are with the user and with the rest of the system.

Wearable user experience

To identify where the wearables should be placed a few considerations were made;

- Skin sensitivity to vibration
- Ease of use (can mobility impaired people put it on themselves?)
- Stigma
- Ergonomics (will the wearable stay on and will it be comfortable enough?)

Looking at all these different factors it was decided to place two wearables directly underneath the users' knees. This will ensure that the user can easily put on the wearables with two hands while sitting down, that they can be worn on or underneath clothes and this area is sensitive enough to feel the vibrations.
The wearables will be available in different colourway to be able to style the system to personal preferences. They will be available in neutral colours to easily match them to any outfit, and in more bold colours for the people that would like to add a statement piece to their wardrobe.

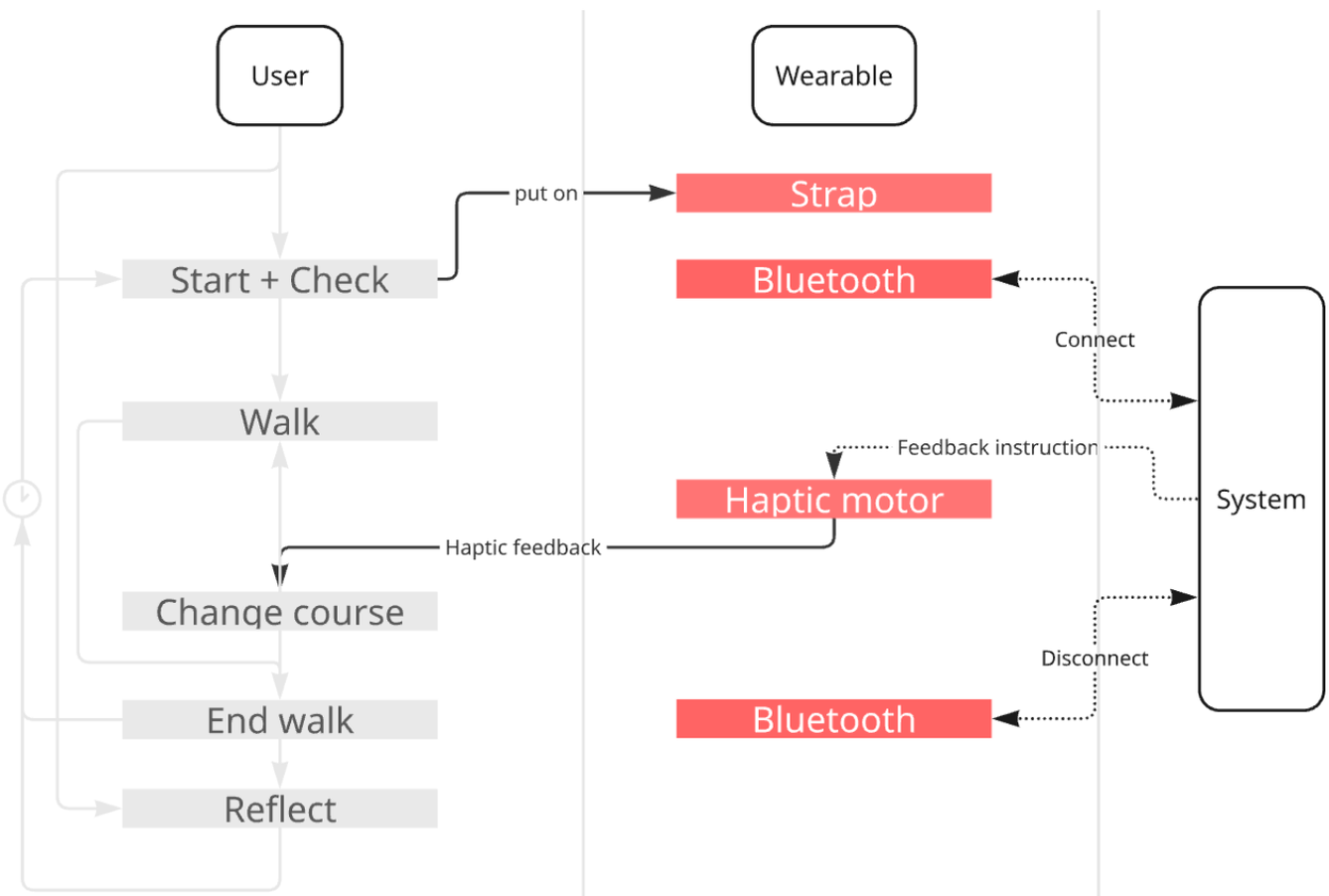


Figure 55: Wearables function chart

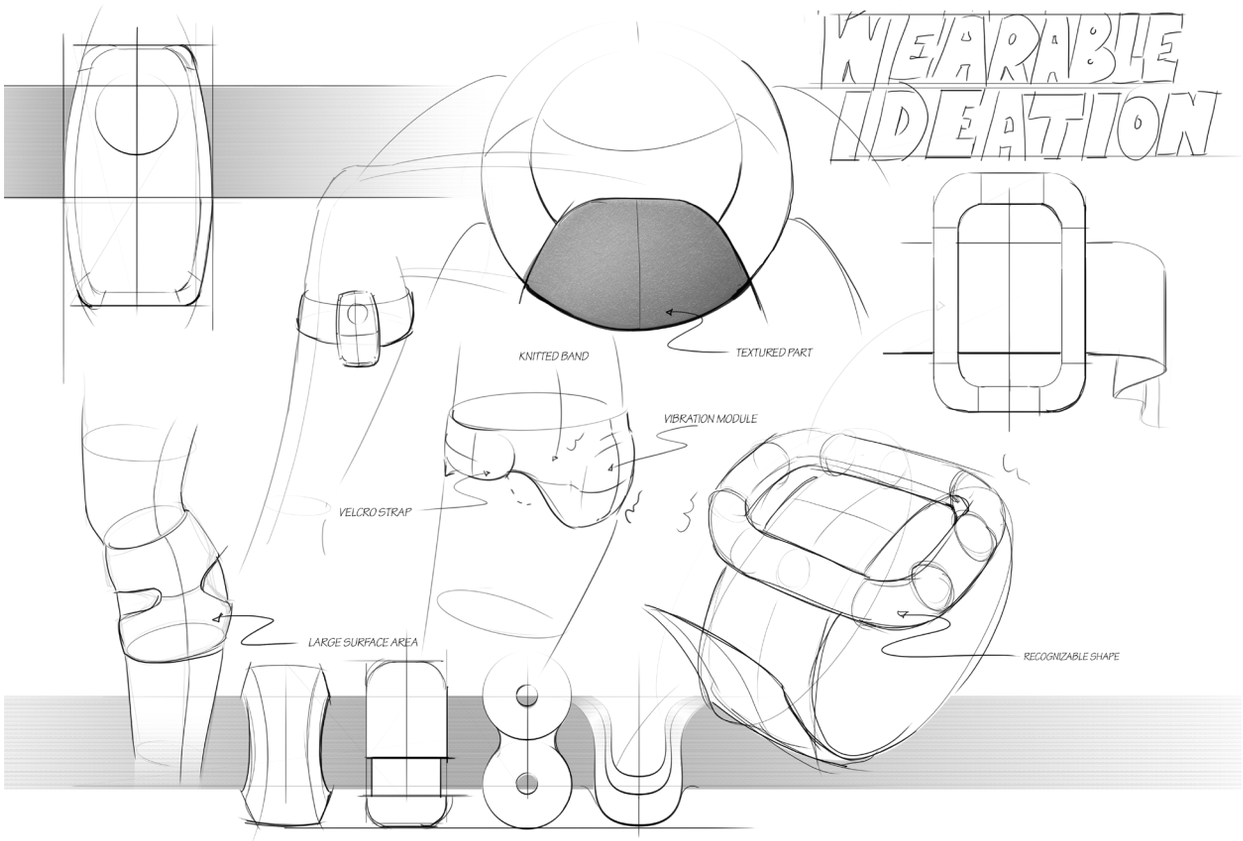


Figure 56: Wearables ideation

Figure 58: Wearable colours (fastening not modelled)

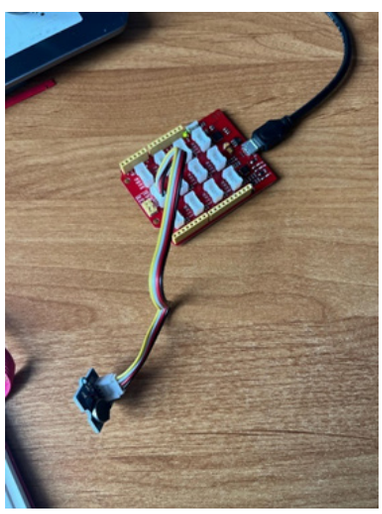


Figure 57: Vibration motor testing

Wearable prototype

To find out what vibrations could be made with a simple coin vibration motor, a low fidelity prototype was made. The components of this prototype and additional documentation can be found in Appendix F: Wearable prototyping components. What was interesting to find was that the vibration motor could produce quite strong vibrations, but that the vibrations are felt very differently throughout the body. A person's fingers and feet are way more sensitive than for example their chest. What was most important was that the vibrations were strong enough to feel on the knee area that the wearable would be sitting (see Figure 57).

Wearable form and dimensions

To ensure this wearable can be worn underneath clothing the design is made to be flat, so it fits nicely under the user their clothes. The device is quite small as it only must receive information from the sensing module and give the user vibration feedback. The design is fitted underneath the user their knee as this gives the user the freedom to choose whether they want the device to be seen by others or not. If not, the user can wear the wearable underneath their clothing, reducing stigma around wearing the device. The dimensions of the product are based on similar wearables that can generate vibrational feedback like the Fitbit (see Figure 60). For ergonomics it is made possible to adjust the wearable to the desired size of the user, the band can be resized to the user's preference.

Wearable materials and parts

For the materials of the wearable there was looked at what other similar wearables are made from. It was chosen to make the strap out of silicone like in Figure 61. The hardware will be in a small metal encasing. The other parts will be 'off the shelf' electronics and a small metal encasing. The components are visualised in Figure 62.

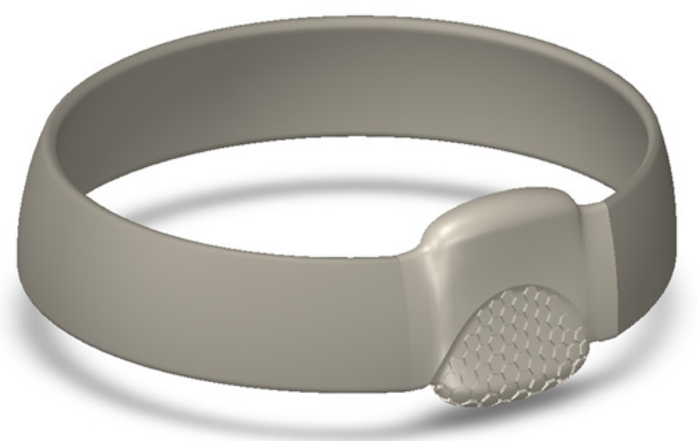


Figure 59: Form of the wearable (fastening not modelled)

Figure 60: Example dimensions of a Fitbit

Figure 61: Example of a silicone wearable (Amazon.ca, n.d.)

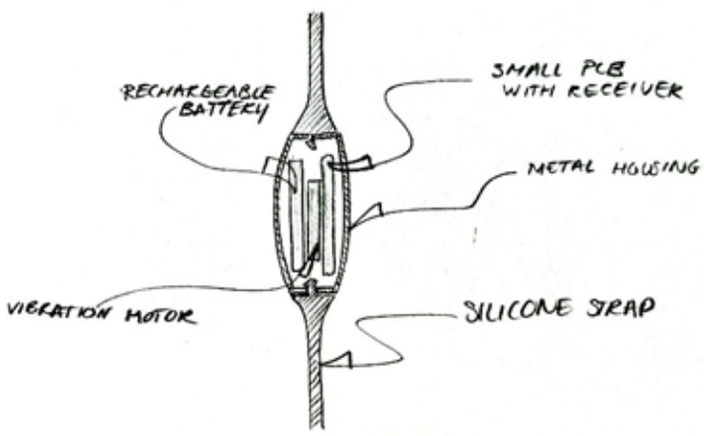


Figure 62: Wearable components

Vibration feedback

To ensure the right kind of feedback and to prove that vibration feedback can substitute tactile feedback that one gets from the white cane, an experiment was conducted. This experiment can be found in Appendix G: User validation research. In this experiment a comparison of vibration feedback was made to a white cane, the participants had to follow obstacle courses with the different kinds of feedback.

The results from this experiment and the conclusion validated that the vibration feedback can substitute the white cane. Further validation can be found in chapter 5.3 User evaluation.

4.4.2 VAMO sensing module

Figure 63: Sensing module

The sensing module functions as the 'eyes and brain' of the system. It captures the environment through a camera, processes the input using a compact computer equipped with AI-based object detection and estimates distances to potential obstacles. The module then sends relevant information wirelessly to the wearables for user feedback.

Designed to be small, efficient and modular the sensing module integrates essential electronics such as the camera, AI vision computer, power source and distance sensor (micro-LiDAR). This section elaborates on the components, their roles, and how they collectively support real-time walking assistance.

Sensing functions

To gain a clear understanding of the functions that the sensing module should perform, a function chart was created (see Figure 64). This chart shows how the sensing module interacts with the user, the environment and the system. It outlines the key steps from capturing visual input to processing and sending feedback signals to the wearable.

Sensing electronics

Components

The main components of the product are a camera, a specialized computer for AI programs for object detection and distancing, and a power source.

Camera

To gather suitable visual input for this project, a camera module is required. Various camera types were considered. The choice of camera depends on what the system needs to detect to function as intended. A wider field of view allows more of the surrounding environment to be captured, which may help improve obstacle detection and situational awareness. For this thesis, the Raspberry Pi Camera Module 3 Wide was selected. This module offers a wide-angle lens that approximates the natural field of view of the human eye, which is considered appropriate for the intended application. Additionally, the module is compact in size, which supports integration into the physical design, and produces a manageable data stream, reducing processing complexity for the system.

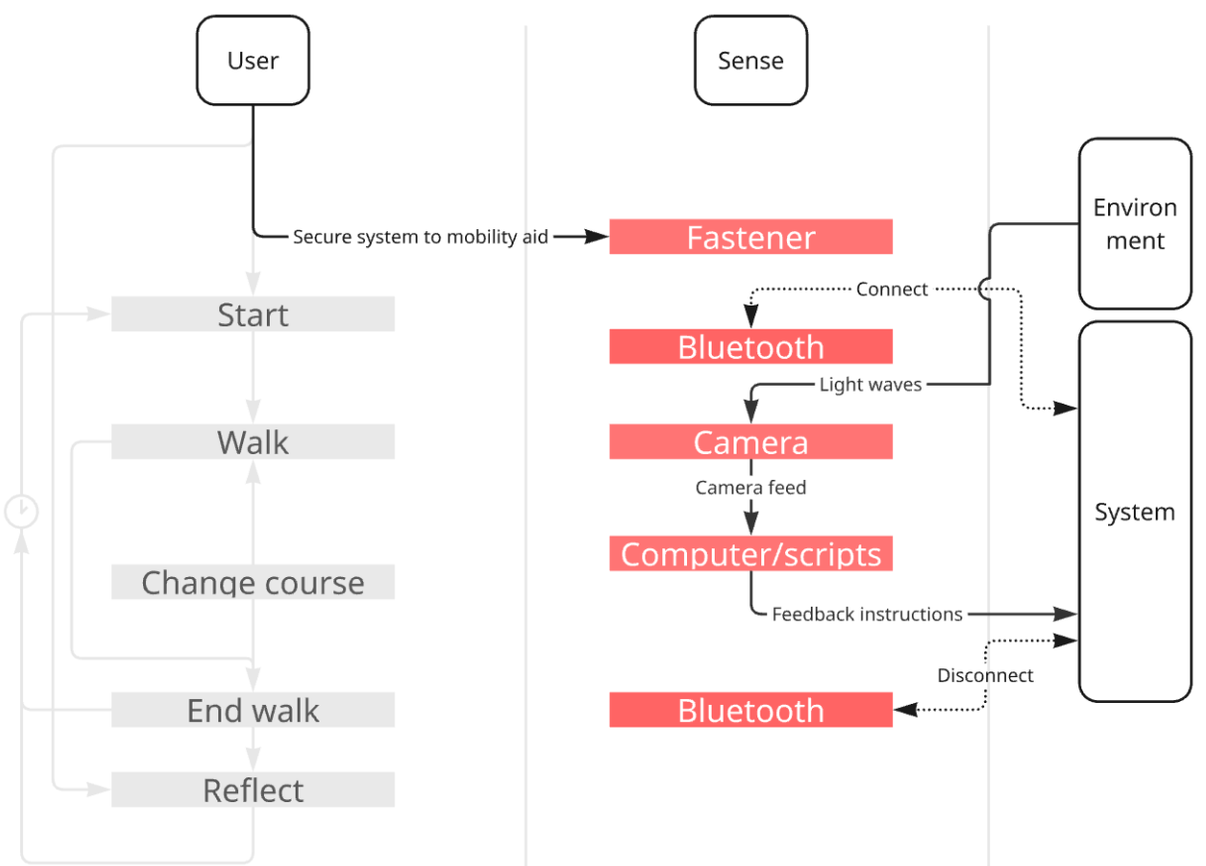


Figure 64: Sensing function chart

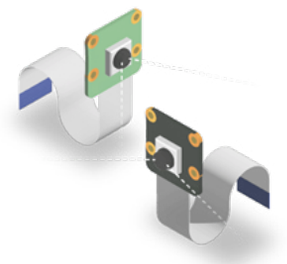


Figure 66: Raspberry Pi camera module 3 wide (1) (Ltd, n.d.)

Figure 67: Arducam mini 2mp plus (2) (Arducam Mini 2MP Plus, n.d.)

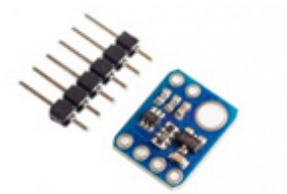


Figure 68: Time-of-Flight distance sensor Micro-LiDAR (1) (VL53L0X Time-of-Flight ToF Afstandssensor, n.d.)

Figure 69: Ultrasonic sensor (2) (Ultrasoon Sensor - HC-SR04, n.d.)

Figure 70: Infrared distance sensor (3) (IR afstands-sensor 10cm tot 80cm - GP2Y0A21YK0F, n.d.)

Figure 71: Li-Po battery (Lithium Polymer (Li-Po) Accu - 3.7V 1200mAh, n.d.)

Figure 65: Example of wide angle view of a camera (5 Mistakes Beginners Make With a Wide Angle Lens & How to Avoid Them, 2015)

Object detection and distancing

Distancing can be done with stereo vision with stereo depth map, LiDAR or ultrasonic sensors or IR ToF sensors. All these sensors have similar low prices. They each have their pros and cons, but since the micro-LiDAR (1) is suitable for different light conditions and is very small this is the best choice for this project. Worth mentioning is the possibility to use stereo vision, this would be done by using two cameras instead of one, just like sighted people have a sense of 3D. This would also be possible, but this is complex to integrate and would be more expensive, therefor adding a simple ToF sensor would be more viable.

Power source

Generally, for these types of applications a Li-Po battery is used, these are rechargeable and reasonably sized and priced. So, this is also the battery used in this project.

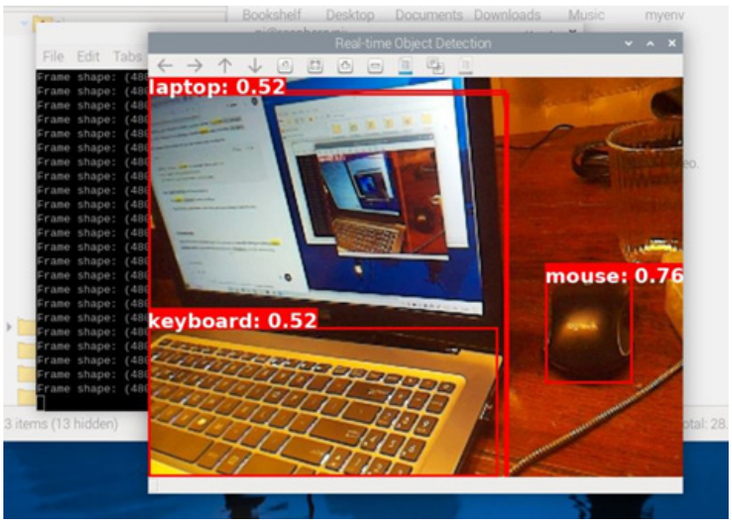


Figure 64: Sensing function chart

Sensing prototype

For this module a prototype was made testing the electronics and the software needed for AI vision obstacle detection (see Figure 72). A more detailed look at this process can be found in Appendix H: Electronics testing (sensing module). Some interesting findings is that it is important to have the right computers that are trained to execute the heavy AI vision tasks. A computer as the raspberry pi 5 in combination with the AI Hat will be able to do real-time object detection and with additional information from the micro-LiDAR will be able to distance the objects. The computer will also need cooling so heatsinks and air cooling can be applied.

Programming and system logic

To operate the sensing and feedback module of the system, various types of programming are required. While the complete setup was not fully implemented due to the scope of this project, an initial prototype was built to test the feasibility of integrating AI-based object detection on a compact embedded system. This was accomplished using a Raspberry Pi 4 model B and the DFine Nano COCO model, a lightweight object detection model well-suited for real time processing (Ustc-Community/Dfine-Nano-Coco · Hugging Face, 2025).

Prototyped components

In the current setup, the Raspberry Pi processes a real-time camera input and uses the object detection model to identify specific objects. A basic object classifier was written in Python and the detection results are filtered using a predefined 'list of trigger objects' relevant to safe navigation for MVIPs. The model runs on the Pi using the 'transformers' and 'torchvision' libraries (Torchvision — Torchvision 0.22 Documentation, n.d.; Transformers, n.d.). These are libraries to support computer vision. This code and setup process can be found in Appendix I: Code modules.

Code modules

To explore and test the functionality of the sensing and feedback system, several code modules were developed. In addition to the implemented elements, a number of additional components are required for full system integration. An overview is provided in Figure 73.

Implemented modules

- Object detection pipeline
  Loads the DFine-Nano-COCO model and continuously processes the camera stream to identify objects.
- Trigger object list
  A first list to filter relevant detections (can be found in Confidential appendix M:)

Modules required for fully implemented system (see Figure 73)

- *Object distancing logic*
  Logic to calculate the relative position and distance of detected obstacles using integrated micro-LiDAR. This module will include distance thresholds to determine whether feedback should be triggered.
- *Feedback condition rules*
  A signal logic that determines which feedback to trigger (vibration pattern, intensity, audio cue) based on:
  - Type of object detected
  - Direction (left/right/centre)
  - Distance threshold
  - Speed of user movement
  - Personal preferences set in the app
- *Communication protocol*
  Bluetooth connection for the computer in the sensing module to send feedback signals to the wearable actuators.
- *Feedback actuation code*
  The wearables, via microcontroller firmware will interpret the signals from the sensing module and activate the vibration motors using PWM or digital output. A quick prototype of this was tested and can be found in Appendix F: Wearable prototyping components. The code used to test this was Arduino code from Github (ArduinoSapienza/Vibration-Motor, 2023/2025).
- *App integration*
  A mobile framework allowing users or caregivers to configure feedback parameters such as vibration strength, pattern, and preferred object types.

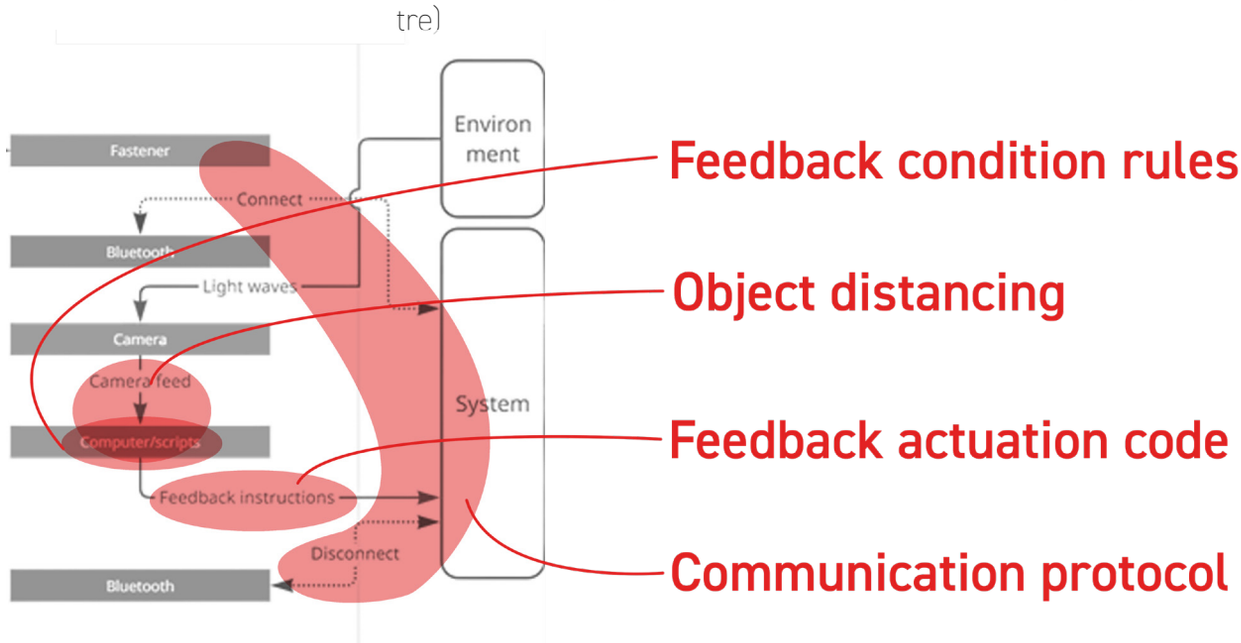


Figure 73: Software implementation in function overview

Sensing aesthetics

The sensing module is designed with a sleek, slim profile to ensure it remains visually unobtrusive when mounted on a mobility aid. Its clean form minimizes distraction while complementing the overall product system. To enhance visibility and social signalling, the module could be produced in recognizable red and white colourway, commonly associated with visual impairment, making it easier for others to identify the user as someone who is blind or has low vision. This dual focus on discretion and recognizability allows users to balance personal preference with situational awareness.

After reviewing the aesthetics of the system after the first form iteration in SolidWorks, it was decided that the parts should become a family. The parts should speak the same form language. To do this the same pattern found on the wearables is translated to the sensing module (see Figure 75).

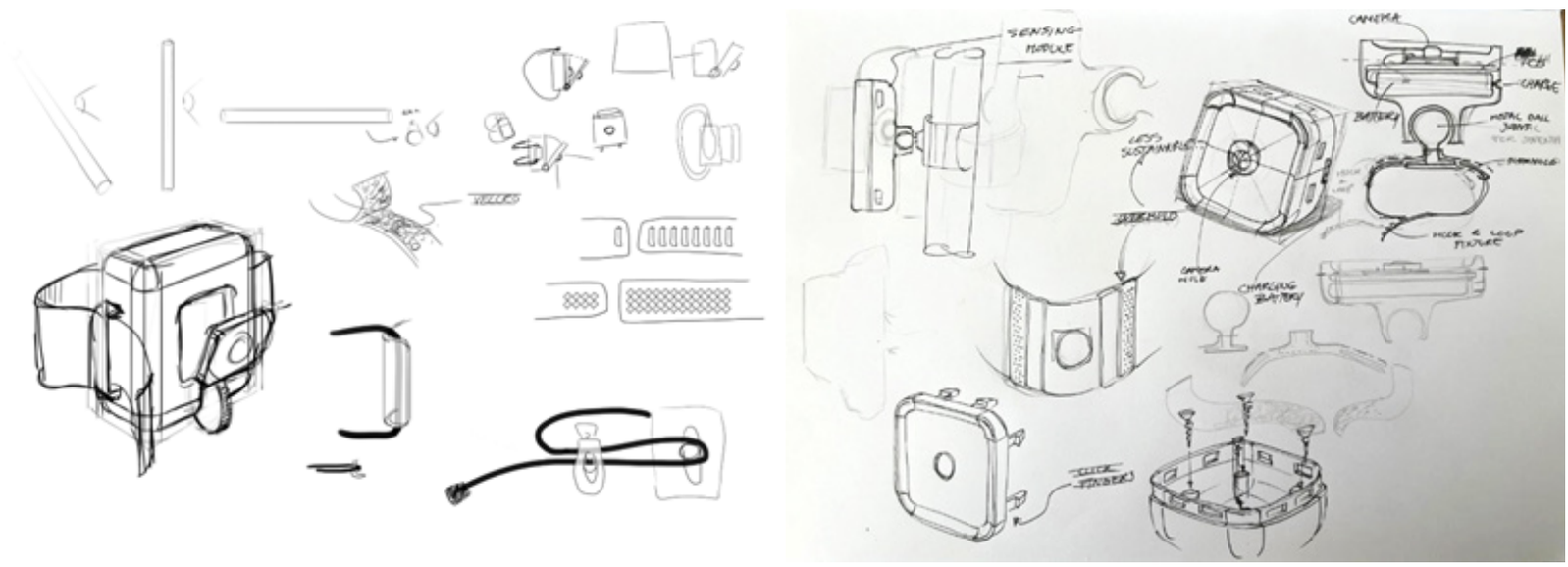


Figure 74: Sensing module ideations

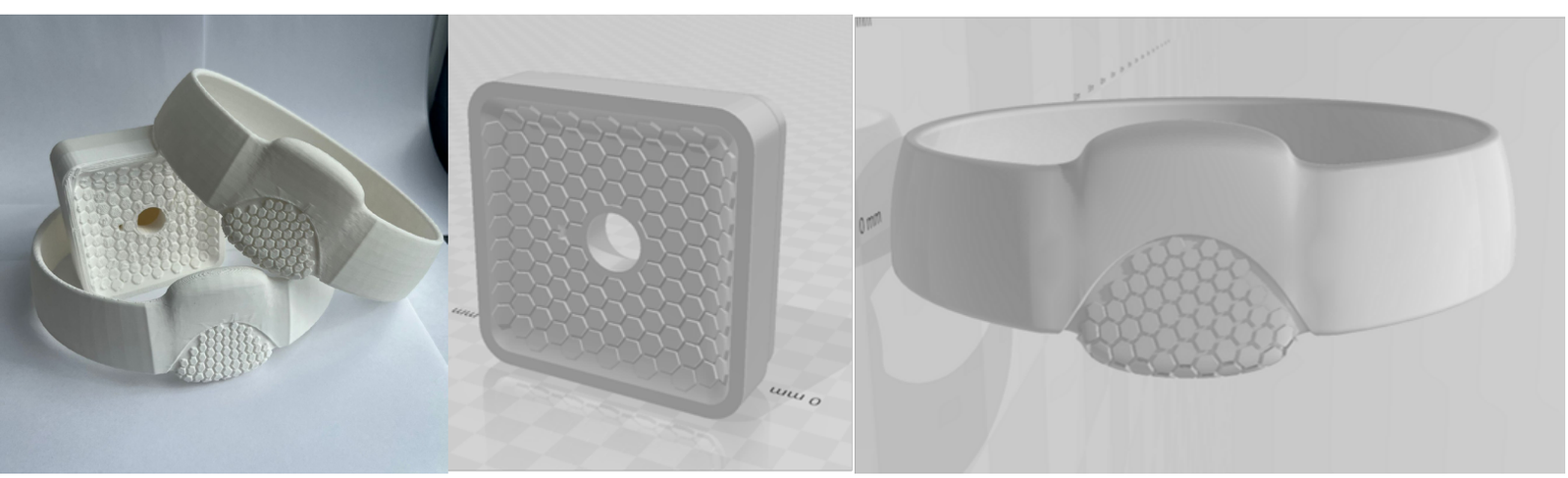


Figure 75: Form family

Figure 76: Prototyping of fastening systems

Sensing fastening system

To fasten the sensing module securely to different walking aids, various attachment methods were explored. These include magnetic fasteners, hook-and-loop fasteners, mechanical clamps, plastic clips and elastic straps with buttons. Each option was assessed based on desktop research and prototyping. These processes can be found in Appendix F: Wearable prototyping components.

While magnetic fasteners such as those from Fidlock , offer excellent usability and longevity, they rely on rare earth materials that are difficult to recycle. Mechanical clamps are durable and recyclable but less user-friendly and modular. Plastic clips are lightweight yet less sustainable due to their short lifespan and because they are made from plastic.

Ultimately, hook-and-lop fasteners showed the most promise. This combination is adaptable to different shapes and user needs and can be produced using recycled or renewable materials ('Shop VELCRO® Brand ECO Collection Industrial Strips', n.d.). For this project, a fastening solution using hook-and-loop straps with a non-slip overmould was selected for its balance of adjustability, reusability and reduced environmental footprint (see Figure 77). Prototyping showed that this method is secure and modular, making it suitable for various walking aids.

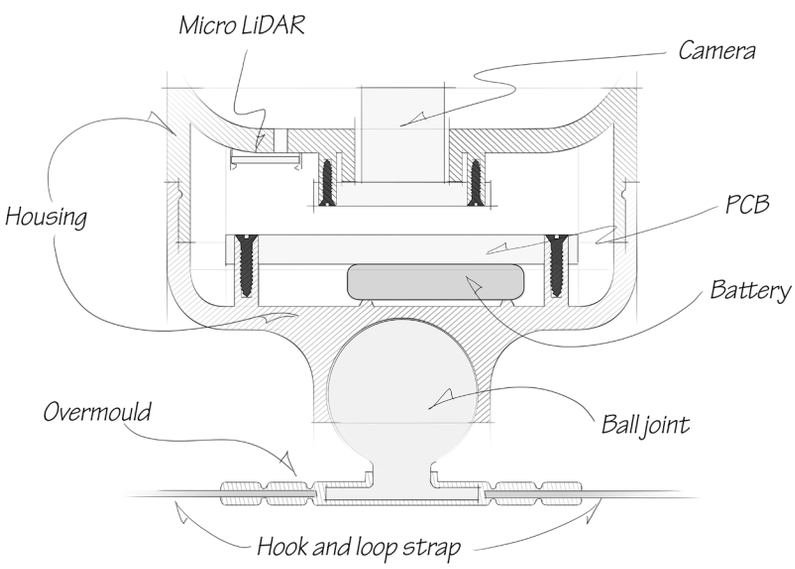


Figure 77: Sensing section and parts

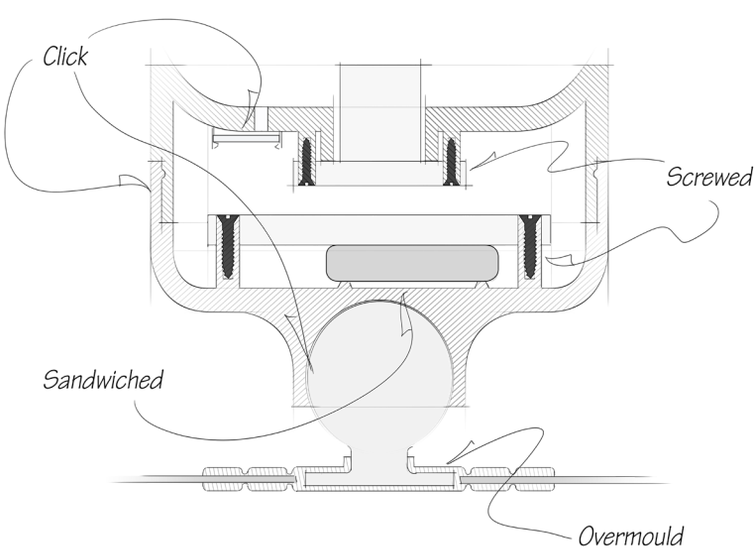


Figure 78: Sensing section with assembly methods

Sensing parts

The sensing module is made up out of different parts, the electronic components were described in the preceding chapter. To clarify the workings of this module, Figure 77 was made. What is interesting to note is the ball joint connects the main housing to the fastening strap, this is done so that the camera can be positioned in the most optimal way. The strap has a hook and loop functionality so it can be fastened modularly to different kinds of walking aids. Room was left open above the custom PCB for the cooling mechanism.

Sensing assembly

The plastic housing of the sensing module is designed to be disassembled for maintenance and repairs. However, two components, the ball of the ball joint and the strap, are permanently fixed through an overmoulded rubber connection. This choice was made to ensure durability, as the straps are subjected to significant mechanical stress during use. By overmoulding these parts, the risk of loosening or failure over time is minimized, contributing to the overall reliability of the system.

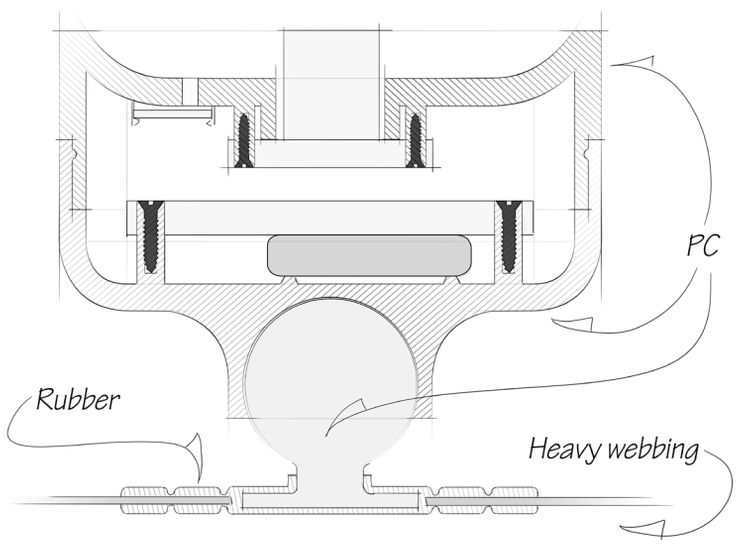


Figure 79: Sensing section with materials

Sensing materials

For the materials of this product some choices were made, the housing should be made of a light weight material (as to not tug on the strap too much) as well as a material that can handle some heat from the electronics as well as other outside factors, because of this a choice was made for poly carbonate, which is often used in housing for electronics. The rubber overmould provides a strong connection between the ball and the strap and also has a non-slip property so the strap does not slip down the tube of the walking aid. The strap is made of a heavy-duty webbing so it can handle some stress.

4.5 Final design

4.5.1 Overview

The final design presents an integrated assistive system that thoughtfully balances functionality, usability, and aesthetics to support safer, more independent navigation for individuals with combined mobility and visual impairments. By addressing both physical and mental barriers, the solution empowers users while blending seamlessly into their daily lives.

Figure 80: System design overview

4.5.2 Key features and user benefits

Features

Obstacle detection
- Real-time identification of obstacles through integrated camera and LiDAR
- Applies feedback logic for directional navigation

Intuitive feedback
- Dicreet vibration cues on the knees for clear spatial awareness
- Directional feedback (left, right, centre)
- Adjustable intensity and pattern for individual needs

Customizable UI and UX
- App interface allows users and caregivers to configure settings
- Personalized feedback modes, object filters, and notification preferences
- UI is designed to be accessible to visually impaired people

Modular design
- Separable components: sensor unit, wearable, and app
- Compatible with various walking aids
- Easy to adapt over time

Guided coaching
- Supports users in learning to interpret the feedback
- Encourages gradual improvement through practice

Seamless product communication
- Bluetooth-enabled link between sensing module and wearable
- Reliable real-time data transfer without physical tethering

Hands-free operation
- Eliminates the need for holding visual aids
- Enhances comfort and confidence during movement
- Enables users to carry items or interact freely with walking aid

User benefits

Self-reliance

Vamo empowers users to navigate their environment without constant assistance. It enables independent mobility, increases freedom of movement and reduces reliance on other humans and visual aids.

Stimulation

By encouraging users to go outside and move with more confidence, the system helps maintain cognitive activity and engagement with the environment, supporting long-term physical and mental health.

Secure

Previously, users had to choose between a walking aid and a visual aid, using both at once was often not possible. This forced a compromise between stability and environmental awareness. VAMO removes that trade-off by offering hands-free obstacle detection and clear vibration feedback. It alerts users in time when something is in their path, reducing the risk of falls and collisions. This not only improves physical safety, but also gives users greater confidence during everyday movement.

Subtlety

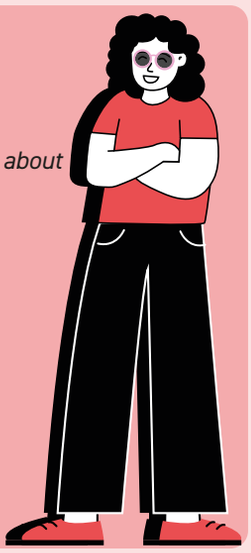
The design is intentionally discreet and modern, allowing it to blend into daily life without attracting unwanted attention. For users who prefer to keep assistive devices private, this subtle approach helps reduce stigma and encourages consistent use in public settings. At the same time, the system offers visual customization options (such as bold colours or worn-over-clothing placement) for users who feel confident expressing their identity through the product. This balance ensures that the system adapts to different comfort levels and personal preferences, without compromising functionality.

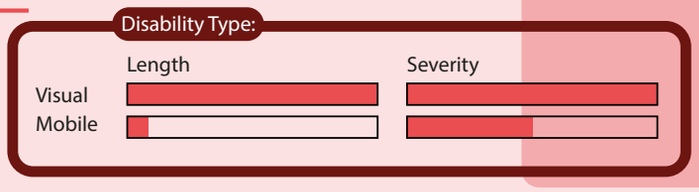
4.5.3 User scenarios

Blind since childhood, Fleur has long navigated the world confidently using a white cane. A recent accident left her with lasting injuries, and she now relies on a rollator or wheelchair for mobility. The combination of blindness and temporary mobility loss challenges her independence in new ways. She's learning to adapt while staying active in her creative work and social life.

"I want to explore new places without worrying about whether I can get around once I arrive."

Fleur

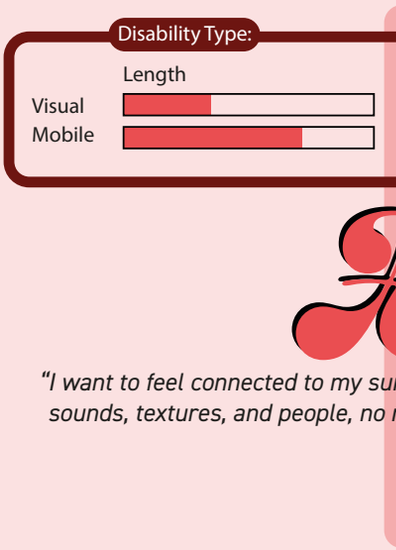




Theo

"I look forward to hearing the stories of each place and feeling the breeze on my face as I walk."

Theo has had trouble walking for many years due to joint issues and now also experiences age-related vision loss. Once an avid gardener and traveler, he's slowed down but remains curious and social. He uses a walker and recently started using a magnifier and voice assistant at home. Adapting to these changes, he values calm environments and clear routines.

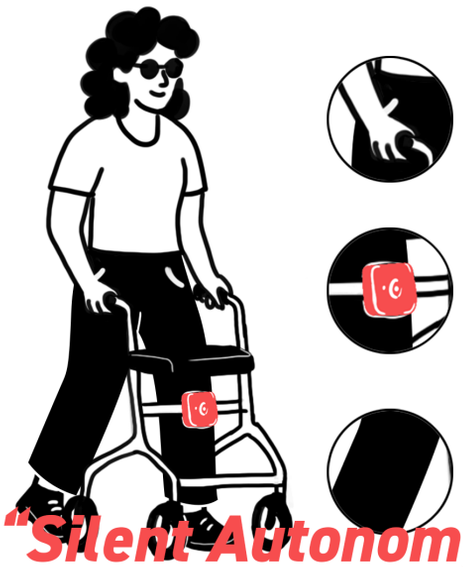


Alex

"I want to feel connected to my surroundings, through sounds, textures, and people, no matter where I go."

Alex lives with a degenerative condition that causes tunnel vision and increasing fatigue. Currently, they see about 60%, but their vision is expected to decline further. Their condition also affects balance and energy, making longer walks difficult. Alex is thoughtful about pacing their days and often uses a cane and navigation app to get around safely.

SCENARIOS

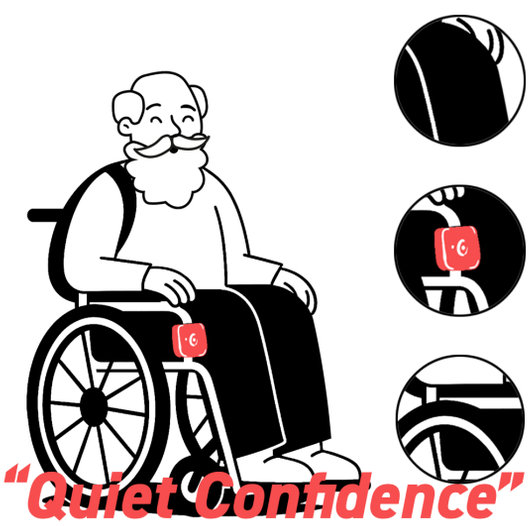


“Silent Autonomy”

1. App use
Fleur does not interact with the app while on the go.
Her app is pre-configured by a support worker to suit her needs.
She might check battery or settings at home using a screen reader, but avoids visual interfaces.

2. Sensing module
Attached to her rollator in a discreet way, without any visible lights or markers.
The module is set to detect major hazards only, like stairs or sharp drop-offs.
It provides essential spatial awareness without making her feel overly assisted.

3. Wearables
Fleur wears the vibration bands under her trousers, out of sight.
Feedback is set to low intensity, with a reduced number of feedback types.
The bands support her without drawing attention to her or replacing her cane entirely.



“Quiet Confidence”

1. App use
Theo uses a tablet version of the app at home, with large buttons and voice guidance.
His daughter helped configure it once; he rarely changes anything himself.
Only checks battery and feedback on/off toggle.

2. Sensing module
Mounted on his rollator with reflective markers for visibility in public.
Set to default sensitivity, with simple alerts for curbs, obstacles, and narrow paths.
Works in the background during his walks without any user adjustments.

3. Wearables
Theo uses the vibration bands daily, with low-frequency feedback.
Feedback alerts him only to essential spatial changes.
Never changes the bands' settings; the system fits into his calm routine.

“Adaptive Balance”

1. App use
Alex actively uses the VAMO app to adjust feedback modes depending on energy levels.
The app interface is customized with large text and dark contrast for remaining vision.
They switch between simplified and standard modes, depending on the situation.

2. Sensing module
The module is always on, providing full detection in both left and right zones.
Occasionally toggles environmental feedback off if overstimulated.
Uses a neutral design without visible assistance cues.

3. Wearables
Alex wears the vibration bands around the knees.
They regularly switch between “active” and “low feedback” modes, based on fatigue.
Feedback types are expanded when in busy or unfamiliar environments.

4.5.4 Rules and certifications

VAMO contains an assistive wearable and digital application aimed at enhancing the independent mobility of MVIPs. As a system that includes electronic components, wireless communication and data processing, VAMO must comply with various European Union directives and regulations (Directorate-General for Internal Market, Industry, Entrepreneurship and SMEs (European Commission), 2015).

To be placed on the European market, the system must have the CE mark, demonstrating compliance with essential safety, health and environmental protection legislation. This includes directives for radio communication (RED, (Directive 2014/53/EU RED, 2014)), electromagnetic compatibility (EMC, (Directive 2014/30/EU EMC, 2014) and the restriction of hazardous substances (RoHS, (Directive 2011/65/EU RoHS, 2011). Furthermore, because the system includes an app that may collect personal user data, the general data protection regulation must also be complied with (Regulation (EU) 2016/679 GDPR, 2016).

In addition to CE marking and GDPR, environmental and product safety regulations such as the Packaging and Packaging Waste Regulation (Regulation - EU - 2025/40 - EN - EUR-Lex PPWR, n.d.) and the WEEE Directive (Directive 2012/19/EU of the European Parliament and of the Council of 4 July 2012 on Waste Electrical and Electronic Equipment (WEEE) (Recast) Text with EEA Relevance, 2012) apply due to the product's physical packaging and electronic nature.

A full overview of applicable directives, explanations, and what this means for VAMO can be found in Appendix L: Regulatory Compliance Overview.

4.5.5 Cost estimation

To assess the economic feasibility of the VAMO system, a production cost estimation was developed in collaboration with an industry expert from Promolding B.V. (Promolding | Creating polymer solutions | Kunststof spuitgietproductie | 3D Printing, n.d.). The system consists of one sensing module and two wearable units. The estimation includes all major costs related to moulds, electronics, assembly, packaging, and logistics. Three production scales were evaluated: 1,000, 5,000, and 20,000 units.

Table 4.1 summarises the estimated cost per unit and projected sales price. The cost per unit decreases at higher volumes due to the fixed investment for tooling being divided over more products, and due to volume discounts on components. A detailed breakdown of all costs, sources, and methods used can be found in Appendix L: Cost Estimation Details.

Scenario	Batch size	Estimated cost price	Estimated sales price
Pessimistic	1,000	147.5	449
Estimated	5,000	76.6	245
Optimistic	20,000	43.1	129

Figure 81: Cost overview of three different scenarios

CHAPTER 5

Evaluation & Validation

5.1 PROTOTYPING |131

5.2 EXPERT EVALUATION |132

5.3 USER EVALUATION |133

5.3.1 FEEDBACK RESEARCH QUESTION |133
5.3.2 FEEDBACK RESEARCH RESULTS |133
5.3.3 FEEDBACK RESEARCH CONCLUSION |135
5.3.4 FEEDBACK RESEARCH DISCUSSION |135

5.4 CONCLUSION |136

5.5 DISCUSSION |138

5.5.1 FEASIBILITY |138
5.5.2 VIABILITY |138
5.5.3 DESIRABILITY |139
5.5.4 LIMITATIONS |139

5.6 RECOMMENDATIONS|140

5.6.1 ADDITIONS |140
5.6.2 IMPROVEMENTS |140
5.6.3 FURTHER DEVELOPMENT |140

5.7 PERSONAL REFLECTION|142

5.0 Evaluation & Validation

In this last chapter, a critical look is taken at the proposed concept. The viability, feasibility and desirability of VAMO were assessed through a validation and evaluation phase. This chapter describes how the design was tested and refined through prototyping, expert consultation and user evaluation. Each method contributed to validating different aspects of the concept.

Physical and digital prototypes were developed to obtain proof of concept of key design features, such as object detection, feedback mechanisms, and fastening systems. Feedback from domain experts helped shape the direction of both the technology and user interaction. Additionally, a user study was conducted to examine whether the vibration feedback could effectively replace the functionalities of a white cane. These efforts not only supported design decisions but also demonstrated the concept's potential. Finally, the chapter concludes with a look ahead and a personal reflection.

Figure 82: Prototyping collage

5.1 Prototyping

As discussed in the previous chapter (4. Elaboration & embodiment of the concept) a lot of different aspects of the design were prototyped, including:

- The AI camera vision
- Fastening systems for the VAMO sensing module
- Vibration feedback
- The VAMO app user interface
- 3D models of the physical parts

These prototypes helped validate the design and gain proof of concept for the more unique solutions within the VAMO design. Some glimpses of the prototyping process can be seen in Figure 82.

5.2 Expert evaluation

Throughout the development of this project, expert feedback played an important role in shaping key design and technical decisions. Multiple experts from diverse domains were consulted, including occupational and physiotherapists, assistive technology specialists and experts from the VR Lab at the TU Delft Library.

Their input guided various aspects of the design process. For instance, during the early stages of technology selection for the sensing module, experts at the VR Lab recommended using an obstacle detection AI-vision system over other sensor setups like radar or stereo vision. This advice led to the implementation of a camera-based object detection system using the DFine Nano COCO model in the prototype (Ustc-Community/Dfine-Nano-Coco · Hugging Face, 2025), running on a Raspberry Pi setup. This approach offered a robust yet lightweight way to detect environmental obstacles is real time and proved to be a technically feasible solution during prototyping (see Appendix H: Electronics testing (sensing module)).

In addition to technical consultations, feedback was also gathered from healthcare professionals regarding the user interaction and feedback modality. Experts confirmed that tactile feedback (vibrations) is highly suitable for users with declining sensory capabilities, as touch often remains reliable even when vision or hearing decline. These insights influenced decisions to focus the design around customizable vibration feedback as the core information channel for the user.

This multi-expert involvement ensured that the final system is not only technically sound, but also grounded in realistic user scenarios and professional practice. Their insights helped bridge theoretical design intentions with practical execution and usability, contributing to the feasibility and acceptability of the concept.

5.3 User evaluation

To validate if the vibration feedback is a sufficient substitute of a white cane, an experiment was conducted. The full research report can be found in appendix G.

5.3.1 Feedback research question

The central research question guiding this study was:

"To what extent is vibration feedback on the knees, compared to the white cane, effective in conveying directional and obstacle information for persons with visual impairment?"

5.3.2 Feedback research results

A total of ten participants took part in the study. All were sighted and experienced simulated blindness through the use of a light-blocking blindfold. The results below represent a selection of relevant findings. The full results can be found in Additional appendices: Research results.

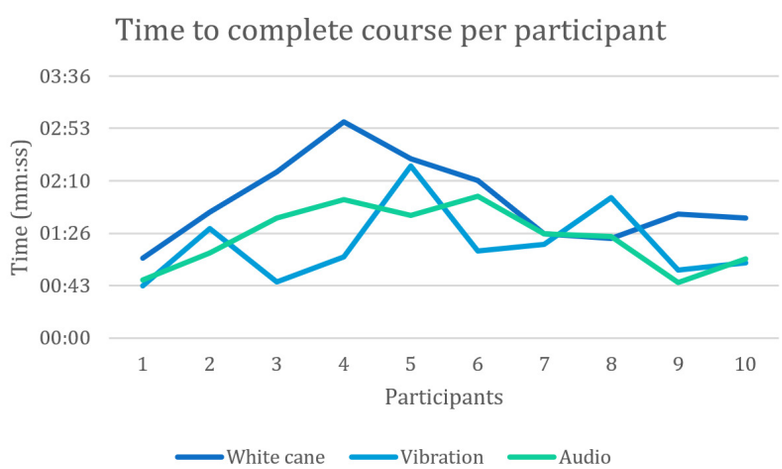


Figure 84: Time to complete course per participant

QUOTE

"It was clear which side [the vibration feedback was on] and [the] right amount of strength"

~ Research Participant

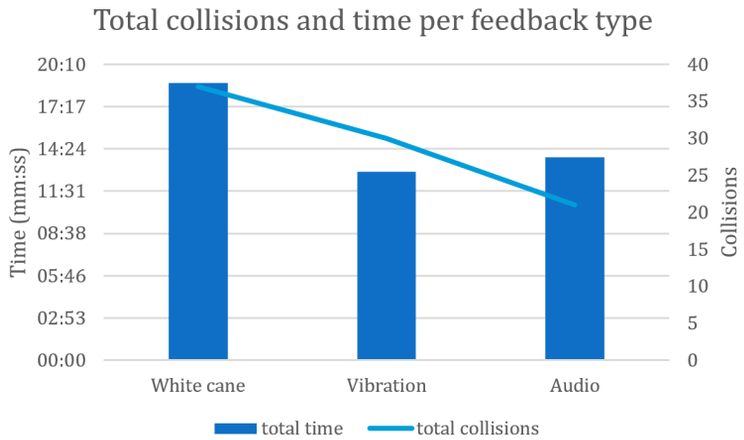


Figure 85: Total collisions and time per feedback type

QUOTE

"Very nice that your hands are free"

~ Research Participant

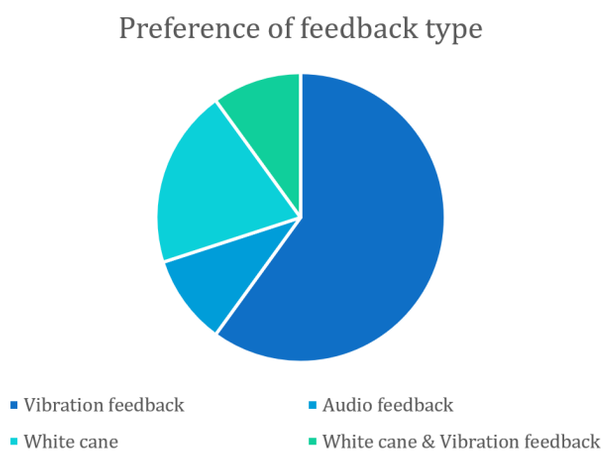


Figure 87: Preference of feedback type

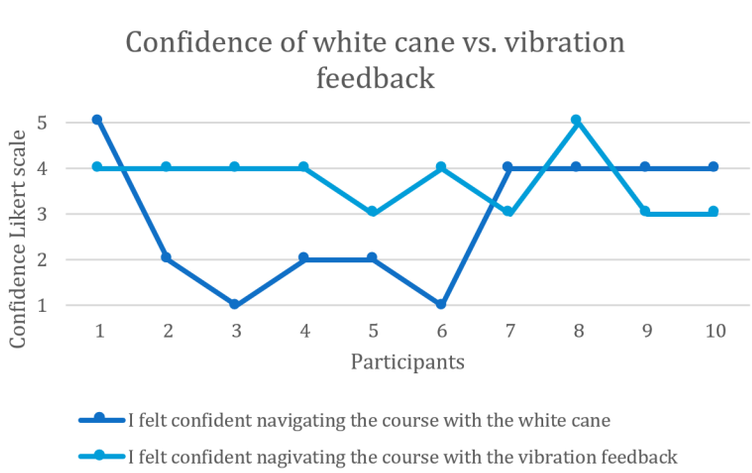


Figure 86: Confidence of white cane vs. vibration feedback

Participants were asked to interpret directional vibrations and navigate through a test setup. Most participants could correctly identify the direction of vibration and responded appropriately to the simulated obstacle cues. Subjective feedback was generally positive.

5.3.3 Feedback research conclusion

Based on the observed outcomes, vibration feedback on the knees appears to be an effective method of conveying directional and obstacle information in the absence of vision. Participants expressed confidence in using the system, with some reporting a preference for it over the white cane in specific scenarios.

When asked whether they believed vibration feedback (if further developed) could replace or complement a white cane, eight out of nine respondents answered that it could replace the white cane, while one participant indicated it could serve as a complement.
These findings suggest that vibration-based navigation has potential as an assistive tool for individuals with visual impairments, particularly if the system is further refined.

5.3.4 Feedback research discussion

The user evaluation showed that vibration feedback on the knees can support directional and obstacle awareness in situations where vision is absent. Most participants were able to interpret the signals correctly and expressed confidence in their ability to navigate with the system. Feedback indicated that the vibration cues were clear, and that the hands-free nature of the set-up was seen as a positive feature. These outcomes suggest that the concept has potential to support safe and independent mobility.

However, all participants were sighted individuals, and vision was blocked using a blindfold. While this allowed for basic testing, it does not fully reflect the experience of people who are blind or visually impaired, especially those with long-term or congenital blindness. The way non-visual information is interpreted, processed, and trusted may differ significantly across user groups. The current test conditions also lacked environmental complexity, which may have influenced the ease with which feedback was interpreted.

Despite these limitations, the evaluation offers useful early insights into how vibration feedback might be experienced by people with limited or no vision. The findings can help shape further development and inform future testing with the intended target group. Additional research is needed to explore long-term use, real-world application, and individual differences in tactile sensitivity, cognitive load, and user preferences.

5.4 Conclusion

This graduation project set out to develop a solution for individuals with combined visual and mobility impairments (MVIPs), a user group that is currently underserved by conventional mobility aids. Through a combination of literature review, field research, stakeholder interviews, and user-centred prototyping, the project resulted in the development of **VAMO**, a modular, app-connected product-service system designed to enhance walking aids with tactile feedback and personalized digital support.

The foundation of the design was built on in-depth research into the diverse needs within the MVIP user group. This included an exploration of functional and emotional barriers such as navigation difficulties, social stigma, dual-task overload, and limited adaptability of existing assistive technologies. In parallel, both technological opportunities, such as LiDAR, haptic feedback, and computer vision, and contextual constraints, including Dutch traffic regulations, age-related mobility limitations, and sensory processing considerations, were examined. These insights informed core design decisions, such as the use of modular wearable components, app-based personalization, and the integration of culturally recognizable visual cues, including the colour scheme of white with red accents.

The design process followed the Double Diamond methodology and included multiple iterations, from ideation and conceptualization to prototyping and validation. Each stage involved stakeholder input, allowing the design to evolve responsively and inclusively. The outcome, VAMO, is not just a technical solution but a system designed to fit into real lives: adaptable, intuitive, and respectful of user identity.

The impact of this design extends beyond the individual user:

- **MVIPs** gain enhanced independence, safety, and dignity. With intuitive tactile feedback, they are no longer forced to choose between a rollator and a white cane. This restores mobility while reducing social stigma and risk of injury.
- **Healthcare providers (HCPs)** benefit from having a modular, adaptive aid they can confidently recommend, knowing it addresses both functional and psychosocial needs. VAMO can reduce care dependency and improve rehabilitation outcomes.
- **Kennis Over Zien** and similar knowledge institutions receive a validated proof of concept that supports their mission of inclusive living, while also contributing new insights into combined-sensory impairments.

- **The government** can see VAMO as a step toward fulfilling EU accessibility directives and SDGs, promoting aging-in-place and reducing the need for institutional care through smarter mobility support.
- **Designers** are encouraged to see assistive technology not only as a functional tool, but as an opportunity to enable self-expression, reduce stigma and foster emotional well-being through aesthetics, identity, and usability.
- **Academia** gains from this project a comprehensive case study in interdisciplinary, inclusive design, showing how engineering, policy and human values can be woven into a coherent, impactful solution.
- Finally, **society** benefits from a more inclusive public space. When MVIPs are seen, heard, and able to participate independently, communities become more accessible, empathetic and just.

5.5 Discussion

5.5.1 Feasibility

The final design of VAMO demonstrates technical feasibility within the scope of this graduation project. A functioning sensing module was prototyped using a Raspberry Pi with a wide-angle camera and preliminary object detection pipeline. Vibration feedback was implemented and tested via microcontroller-driven wearables. Early user testing confirmed that directional haptic feedback is interpretable and effective in simulated low-vision conditions. While full real-time integration and long-term testing remain out of scope, the chosen technologies, such as LiDAR, open-source object detection models, and Bluetooth communication, are considered accessible, scalable, and adaptable. Further engineering development is needed for robust performance in dynamic, outdoor environments and integration with commercial walking aids, but the core concept has been validated.

5.5.2 Viability

The solution shows potential to be viable from a business and implementation perspective. By designing modular add-ons instead of a new rollator, the product can be retrofitted to existing devices, increasing market accessibility and reducing cost. The modular approach also aligns with growing trends in the mobility aid sector toward personalization and flexible upgrades. From stakeholder interviews and expert feedback, it is evident that healthcare professionals are open to recommending such products if they prove effective, easy to use, and reasonably priced. Viability could be further improved by pursuing insurance reimbursement or institutional adoption through care homes. A cost estimation was made, and off-the-shelf components are currently affordable for prototyping; future optimization could reduce costs even further (read more about this is in chapter 4.5.5 Cost estimation).

5.5.3 Desirability

Desirability was a central focus of the design process. The product addresses both functional and emotional needs of MVIPs by reducing reliance on stigmatized aids like the white cane while supporting independence and safety. Through interviews and user testing, it became clear that discretion, hands-free operation, and comfort are key design drivers. The customizable look and feel of the wearables, and the app-based configuration, contribute to a product that can adapt to personal preferences and offer a sense of ownership. The design considers aesthetics, self-expression, and mental barriers which are important factors in promoting consistent, confident use of the product in public.

5.5.4 Limitations

Despite promising results, there are some limitations to VAMO.

First of all, in the research analysis some numbers are posted about the size of the target group. The World Health Organization (WHO) reports noticeably higher estimates of blindness compared to other sources. This discrepancy is likely due to the WHO's extensive research methodology, which accounts for unreported and undiagnosed cases, offering a more comprehensive global perspective on visual impairment. But could be researched further to get a better grip on the actual volume of the target group for better estimations to for instance calculate the batch size of the product.

Furthermore, user testing was conducted with sighted participants under simulated blindness, which does not fully replicate a comprehensive understanding of experiences or sensory adaptation of people with long-term visual impairment. The sensing module was tested in controlled environments, and real-world accuracy, responsiveness, and robustness remain to be validated. Furthermore, the current feedback logic is rule-based and not yet dynamically adaptive to different users or environments. Long-term comfort, battery life, and real-time performance under daily use are also areas requiring further development. Finally, while the app prototype supports customization, the digital interface has not yet been tested with users who have significant visual impairments.

5.6 Recommendations

5.6.1 Additions

- **Add low-light vision capabilities:** Implement night vision or infrared cameras to improve performance in dark environments.
- **Integrate light sensors:** Detect lighting conditions and automatically switch to the appropriate camera.
- **Add lights to the sensing module:** Allow users to turn on/off external lights for visibility and safety.
- **Integrate with online map services:** Connect to Google or Apple Maps to support navigation assistance.
- **Add podcast-based coaching features:** Develop auditory content to support onboarding or user motivation.

5.6.2 Improvements

- **Optimize fastening systems:** Ensure that the fastening system can be switched quickly and accessibly for users who often switch between walking aids.
- **Address lens fogging/water issues:** Apply hydrophobic coatings or protective housings for rain resistance.
- **Conduct full user testing:** Validate the system with MVIPs in real-life scenarios.
- **Expand user research base:** Include VIPs, MIPs, and caregivers in design iterations.
- **Material testing:** Poly Carbonate was deliberately chosen for its material properties, but does have weaknesses, therefor it would be wise to do some additional research into this material.

5.6.3 Further development

- **Develop advanced object detection scripts:** Train specialized models for differentiating obstacle types and user intent.
- **Enhance pedestrian detection:** Improve person-tracking accuracy and predict movement paths to avoid collisions.
- **AI recognitions for static and dynamic obstacles:** Use motion tracking and AI to distinguish object types and behaviours.
- **Integrate adaptive feedback systems:** Adjust vibration feedback based on user response time or stress levels.
- **Research vibration feedback patterns:** Study which feedback patterns are most effective for different contexts.
- **Explore adding alternative feedback modes:** Consider audio, thermal, or other haptic technologies.
- **Collaborate with tactile feedback experts:** Work with companies like Elitac to implement richer tactile communication.

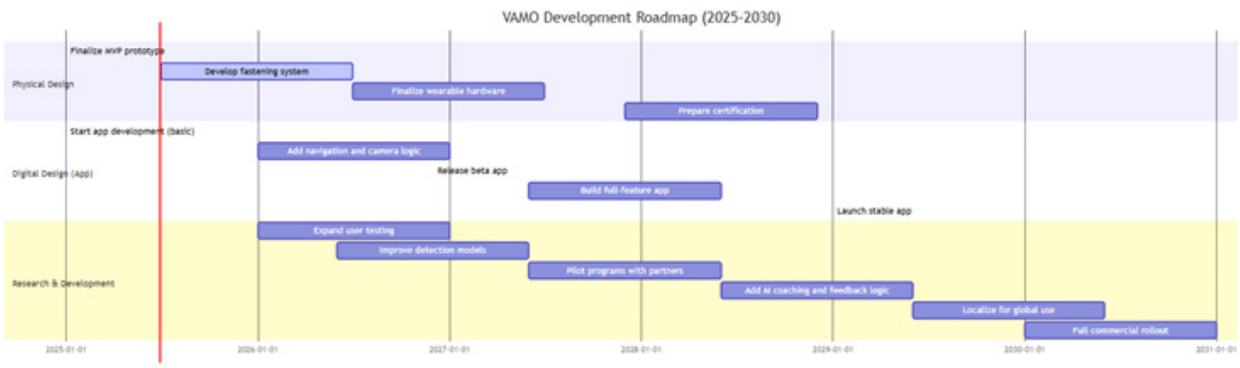


Figure 86: Vamo development roadmap (2025-2030)

2025

- Finalize MVP prototype and user testing with small groups
- Begin collaboration with hardware/software partners (e.g. Elitac, camera manufacturers)
- Initiate app development (basic functions + user testing)
- Apply for grants or start seeking funding

2026

- Expand user testing with larger, diverse populations
- Integrate improved object and pedestrian detection models
- Add map navigation support and camera switching
- Launch beta version of the app

2027

- Begin regulatory preparation (safety compliance, CE marking, accessibility checks)
- Develop wearable module with final materials
- Finalize fastening system design
- Initiate pilot programs with assistive organizations

2028

- Launch fully functioning product-service system in test markets
- Begin marketing and awareness campaigns
- Start collaboration with healthcare providers for system integration

2029

- Refine based on market and user feedback
- Add AI enhancements (adaptive feedback, coaching logic)
- Expand to more countries and support languages

2030

- Full commercial rollout
- Begin updates based on real-time usage data
- Explore adjacent products (e.g. solutions for wheelchair users or public space integration)

5.7 Personal reflection

After this intensive half year period of graduating, I would like to look back on my time as a graduation student and my student journey in general.

Coaching and company

My coaches who helped me a lot through this project were a great help. A lot of sessions were held almost weekly to discuss the progress of my project. Especially in the first period of the project there was a lot to discuss about the company which I initially worked with. Because we could not agree on a good contract between the parties we had to decide to cancel this collaboration unfortunately. This felt like a big setback for me, the decision was finalised quite late in the project, during the midterm period, and caused me a great deal of stress. Fortunately, looking back on this change of course, it was a chance for me to really fit this project to my personal interests. It gave me more freedom to do the right thing, and I can say I am very proud of what I delivered all on my own. The moments where I did feel that it would have been very handy to use the resources and knowledge of the company, it would have been more convenient and quicker to use those when working at a company. But, in the end I got all the resources and knowledge I needed from other places, fortunately I had a project subject that not only I am passionate about. So, during that period it was nice to have my coaches. I have to say, I think that I could've gotten more out of the coaching sessions, in the future I would like to focus more on preparing these types of meetings to optimally use peoples time and expertise.

Project management

On the topic of project management, I think I learnt a lot and also still have a lot to learn. After finishing my internship, I got the feedback that learning project management is a very valuable thing and is something that you learn by doing. Well, this graduation project is obviously a very good example where good project management is essential. Project management is also quite hard I have learnt, particularly when working alone. When there is less time pressure, I was more likely to postpone the more difficult tasks. I would still be productive but leave the more challenging tasks to 'tomorrow me'. This finally led to the 'tomorrow me' being way more stressed in the deadline days as only the challenging things were left (a bit exaggerated). Those challenging things are often also the most effective and valuable tasks, so having to skip some of those is also more stressful but was sometimes necessary as time was running out. This is something I will have to keep telling myself.

What is also is true is that I find those challenging tasks way more challenging when I must do them alone. In my head the graduation project is something you must do on your own, but I learned that that doesn't have to be that way at all. As my coaches also told me, you can delegate tasks or do them together with others. This revelation certainly helped me a lot, mostly at the end of my project, and I wish I had accepted that though earlier.

Finally, something that I have struggled with for longer is perfectionism. I give myself quite a hard time sometimes, sometimes that leads to better results and high-quality work, which I think I also delivered in this thesis, but it sometimes immobilizes me as I don't want to start doing things as I only want to do them perfectly. What I learnt from this graduation project is that things don't always have to be perfect to be valuable and

Work/life balance

Working alone instead of in a team is something you don't do very often during the master or Bachelor of Industrial Design. This graduation project was in a lot of facets applying knowledge and skills learnt throughout the studies but in another way a totally new way of working. Because working alone you get to schedule your own hours it is easier to shuffle around a bit more and that leads to a less evenly spread workload during the project. I found it sometimes difficult to keep a good balance between work and leisure time. Where in the deadline days I was working lots of hours and having little time to relax. I felt in my body that that was not very good for me. I aspire to do this differently in the future for solo projects although I am looking to work in teams.

End of life as a student

Finally, this project concludes my life as a student, for now at least. It is a weird realization that after this last project, I will no longer be studying to become a designer, I will be a design engineer. That is scary and super exciting at the same time. As of now, my future is still open and I do not know what I will be doing in a year from now, again that is scary and exciting. This last year I have certainly become confident in my upcoming role as a designer and looking back at my bachelor ending project vs my graduation project I have progressed a lot. I am very proud of this project and so very happy to have had the opportunity to design for this wonderful cause. I realized that for me, helping people with my work gives me an immense satisfaction. I will strive to keep on working to better the world. With that being said, I would like to conclude this thesis where I have learned so much from and worked so hard on.

CHAPTER 6

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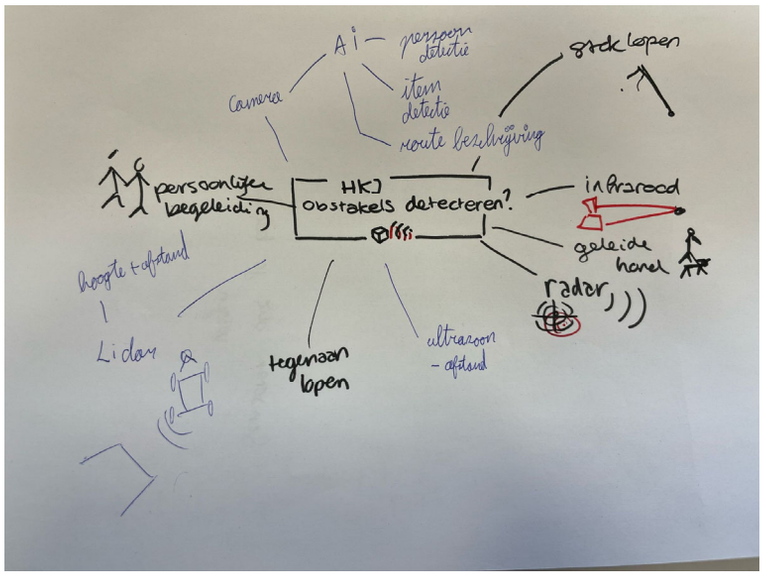
CHAPTER 7

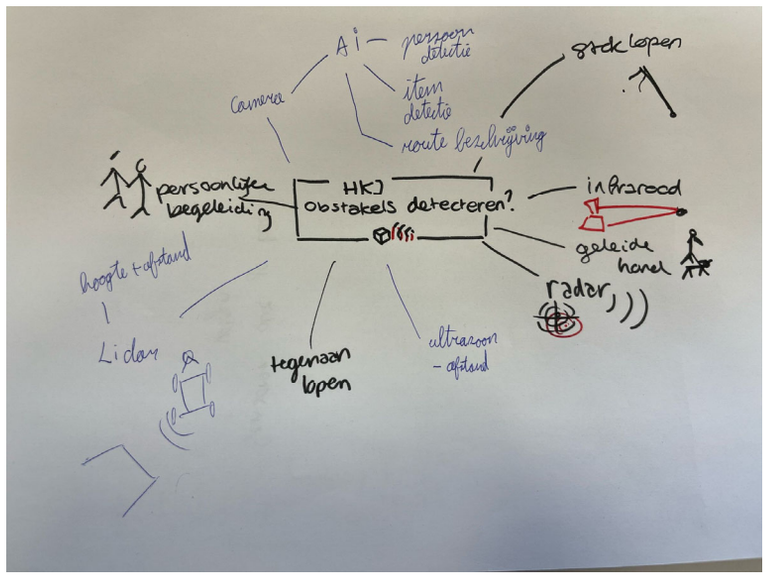
Appendices

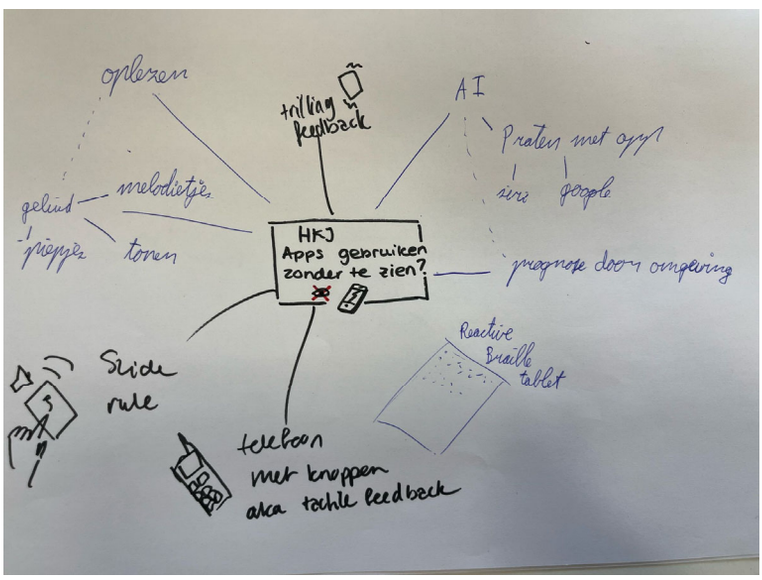
Appendix A: Related research

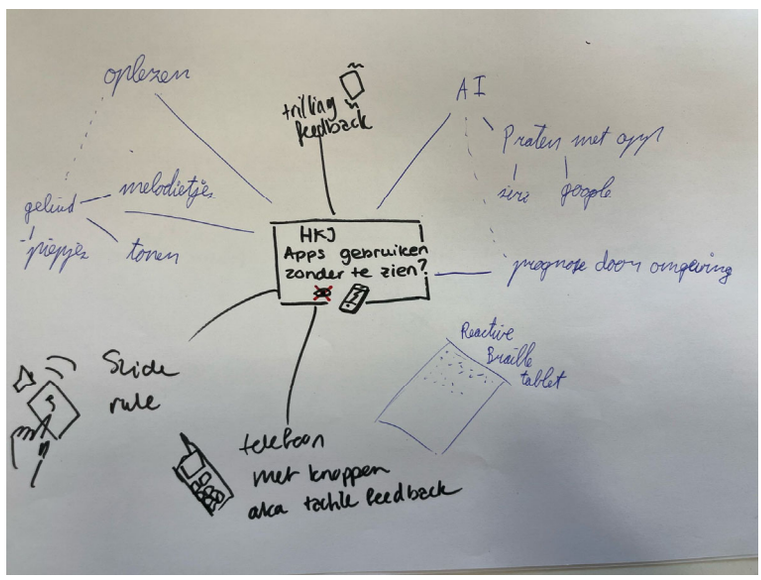
- *Late 1990s: "PAMM - a robotic aid to the elderly for mobility assistance and monitoring: a "helping-hand" for the elderly"* (Dubowsky et al., 2000)
- *(Pre) 2000: "A smart walker for the frail visually impaired"* (MacNamara & Lacey, 2000)
- *Early 2000s: "The Evolution of Guido"* (G. J. Lacey & Rodriguez-Losada, 2008)
- *2010: "Foogue: eyes-free interaction for smartphones"* (Dicke et al., 2010)
- *2012: "Ultrasonic spectacles and waist-belt for visually impaired and blind person"* (Bhatlawande et al., 2012)
- *2013: "Usability and Design Guidelines of Smart Canes for Users with Visual Impairments"* (Kim & Cho, 2013)*; "Obstacle detection by the Kinect cane system for the visually impaired"* (Orita et al., 2013)
- *2015: "Real-Time Obstacle Detection System in Indoor Environment for the Visually Impaired Using Microsoft Kinect Sensor"* (Cummings et al., 2014)*; "Vision-Based SLAM and Moving Objects Tracking for the Perceptual Support of a Smart Walker Platform"*(Panteleris & Argyros, 2015)
- *2016: "c-Walker: A Cyber-Physical System for Ambient Assisted Living"* (Rizzon et al., 2016)
- *2017: "ISR-AIWALKER: Robotic Walker for Intuitive and Safe Mobility Assistance and Gait Analysis"* (Paulo et al., 2017)
- *2018: "Supporting rehabilitation prescription compliance with an IoT-augmented four-legged walker"* (Zehtabian et al., 2018)*; "An Autonomous Simultaneous Localization and Mapping Walker for Indoor Navigation"* (Kashyap et al., 2018)*; "Wearable Smart System for Visually Impaired People"* (Ramadhan, 2018)*;*
- *2019: "Detecting Unsafe Use of a Four-Legged Walker using IoT and Deep Learning"* (Khodadadeh et al., 2019)*; "Smart Walker for the Visually Impaired"* (Feltner et al., 2019)*; "Reinforcement Learning Aided Robot-Assisted Navigation: A Utility and RRT Two-Stage Approach"* (Garrote et al., 2020)
- *2021: "A Smart Walker for People with Both Visual and Mobility Impairment"* (Mostofa et al., 2021)
- *2018: LEA Robot (Lean Empowering Assistant Care Robot) released by Robot Care Systems* (Capelle, 2017; *CLICKNL*, n.d.)

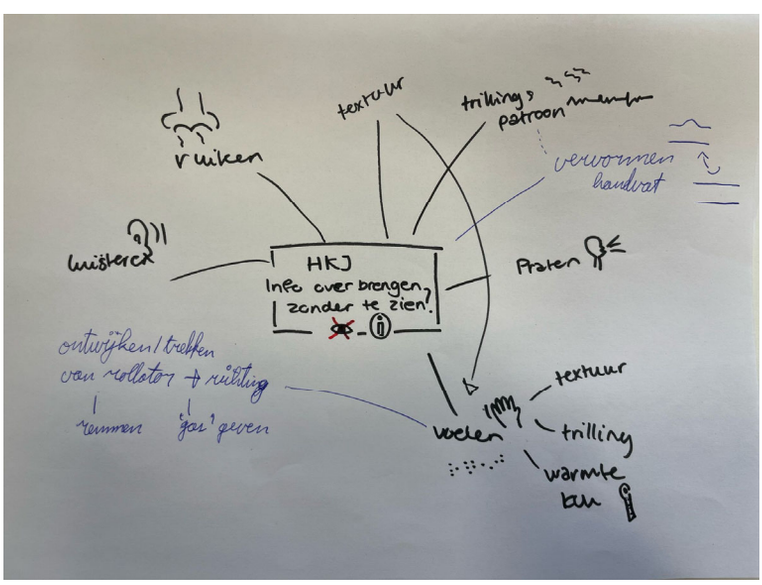
Appendix B: HKJ's

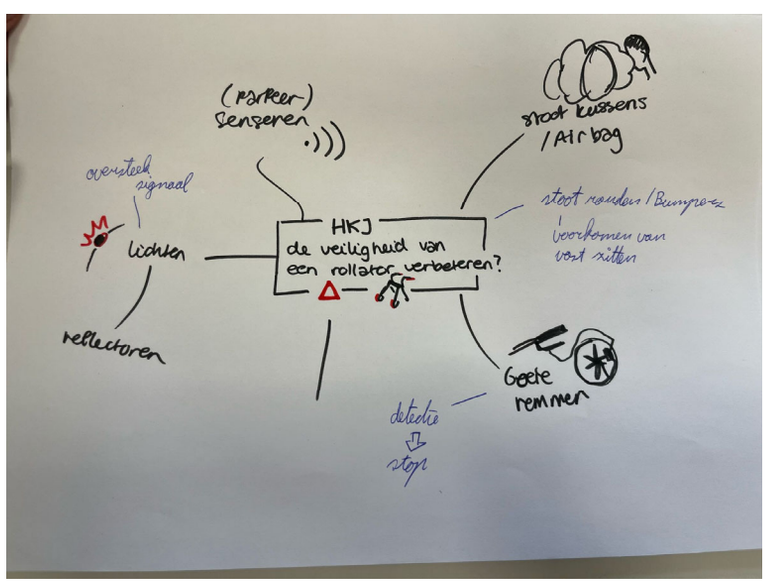












Appendix C: Laws of VIP's in traffic

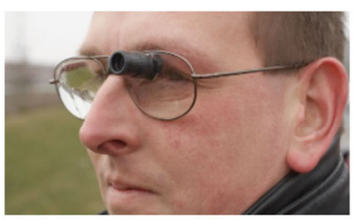
Voor het besturen van dergelijke voertuigen op de openbare weg zijn wettelijke bepalingen waaraan iedereen moet voldoen. Je mag niet zonder meer autorijden als:

- De gezichtsscherpte met twee ogen samen lager is dan 0,5
- Het horizontaal gezichtsveld kleiner is dan 120 graden of als het bereik kleiner is dan 50 graden naar links of naar rechts.
- Het verticale gezichtsveld minder is dan 20 graden naar boven en 20 graden naar beneden.
- Er uitvallen in het gezichtsveld zijn binnen een straal van 20 graden vanuit het centrum.

Uitzonderingen - Bij gezichtsscherpte 0,4-0,5

In uitzonderlijke omstandigheden kunnen personen met een gezichtsscherpte tussen 0,4 en 0,5 geschikt worden verklaard voor rijbewijzen van Groep 1 (gebruik personenauto voor prive doeleinden). Voorwaarden zijn de afwezigheid van andere visuele functiestoornissen, een positief advies van een oogarts en een positieve rijgeschiktheidstest afgenomen door het CBR.

Uitzonderingen - Bij gezichtsscherpte lager dan 0,5



Is de gezichtsscherpte lager dan 0.5 en kan middels de hierboven beschreven uitzondering geen rijbewijs behaald worden, dan is er soms de mogelijkheid om toch auto te rijden met behulp van een Bioptisch Telescoop Systeem (BTS). Een BTS is een bril op sterkte waarin bij één oog een kleine telescoop geplaatst is boven in het brillenglas. Hierdoor wordt de bestuurder in staat gesteld om details waar te nemen zoals verkeersborden en verkeerssituaties in de verte door een kleine knik met het hoofd te maken en kort door de telescoop te kijken. De bestuurder mag daarnaast geen gezichtsvelduitval hebben. Voor meer informatie, ga naar www.cbr.nl en www.auto-mobiliteit.org. Rijden met een BTS mag alleen in een auto met automatische versnellingsbak.

(Burg, 2023)

Appendix D: Walking aids

- (Leonard, 2017)
- Handheld support devices
    - support cane / walking stick

(*Adjustable Classic Walking Stick - Astro Group*, n.d.)

    - quad cane (four small legs at bottom for stability

('RG5610 -Quad Cane -Base', n.d.)

    - hemi walker

(*Hemi Walker - Invacare*, n.d.)

- Framed walking aids
    - standard walker / Zimmer frame (no wheels, lifted up each step)

(*Lightweight Zimmer Frame - Walking Frames Medium Ultra Narrow from Essential Aids*, n.d.)

- Two-wheeled walker (front wheels, back legs with rubber tips)

(*Medline Extra-Wide Two-Button Heavy Duty Wheeled Walker*, n.d.)

- Four-wheeled walker (rollator) (with brakes, seat and basket)

(*Amazon.Com: Drive Medical 10257RD-1 4 Wheel Rollator Walker With Seat, Steel Rolling Walker, Height Adjustable, 7.5" Wheels, Removable Back Support, 300 Pound Weight Capacity, Red : Health & Household*, n.d.)

- Three-wheeled walker (tri-walker) (more maneuverable, less stable than rollator)

(‘Days Three Wheeled Rollator Walker’, n.d.)

- Posterior walker (placed behind the user, often used by children with cerebral palsy)

(*Nimbo Lightweight Posterior Posture Walker (In Flame Red) – Townfield Mobility*, n.d.)

- Upright walker (taller handles to encourage a straighter posture)

(*Upright Walker-Series T - Standing Mobility Support — Vive Health*, n.d.)

- Wheeled mobility aids
    - Rollator with integrated wheelchair seat (Rollz Motion)

(*Rollz Motion 2.1 Rollator Rolstoel | Rolstoel en rollator in 1*, n.d.)

- Wheelchair

(*Medline Folding Wheelchair with Flip-Back Arms, Nederland | Ubuy*, n.d.)

- Knee scooter / knee walker (for lower leg injuries)

(*Knee Walker | Integrant*, 2021)

- Walker with forearm supports / platform walker (for those who can’t grip handles)

(*Heavy Duty Forearm Walker with 2 Castors | Active Mobility*, n.d.)

- Mobility support devices with additional features
    - Mobility scooter

(*Rent a Mobility Scooter - Rent a Mobility Scooter in the Friesland Area!*, n.d.)

- Exoskeleton walking aid

(Hanlon, 2013)

- Smart walker

(*Camino*, n.d.)

- Rehabilitation gait trainer

(‘Gait Training Frame Medical Unweight Walking Training Frame’, n.d.)

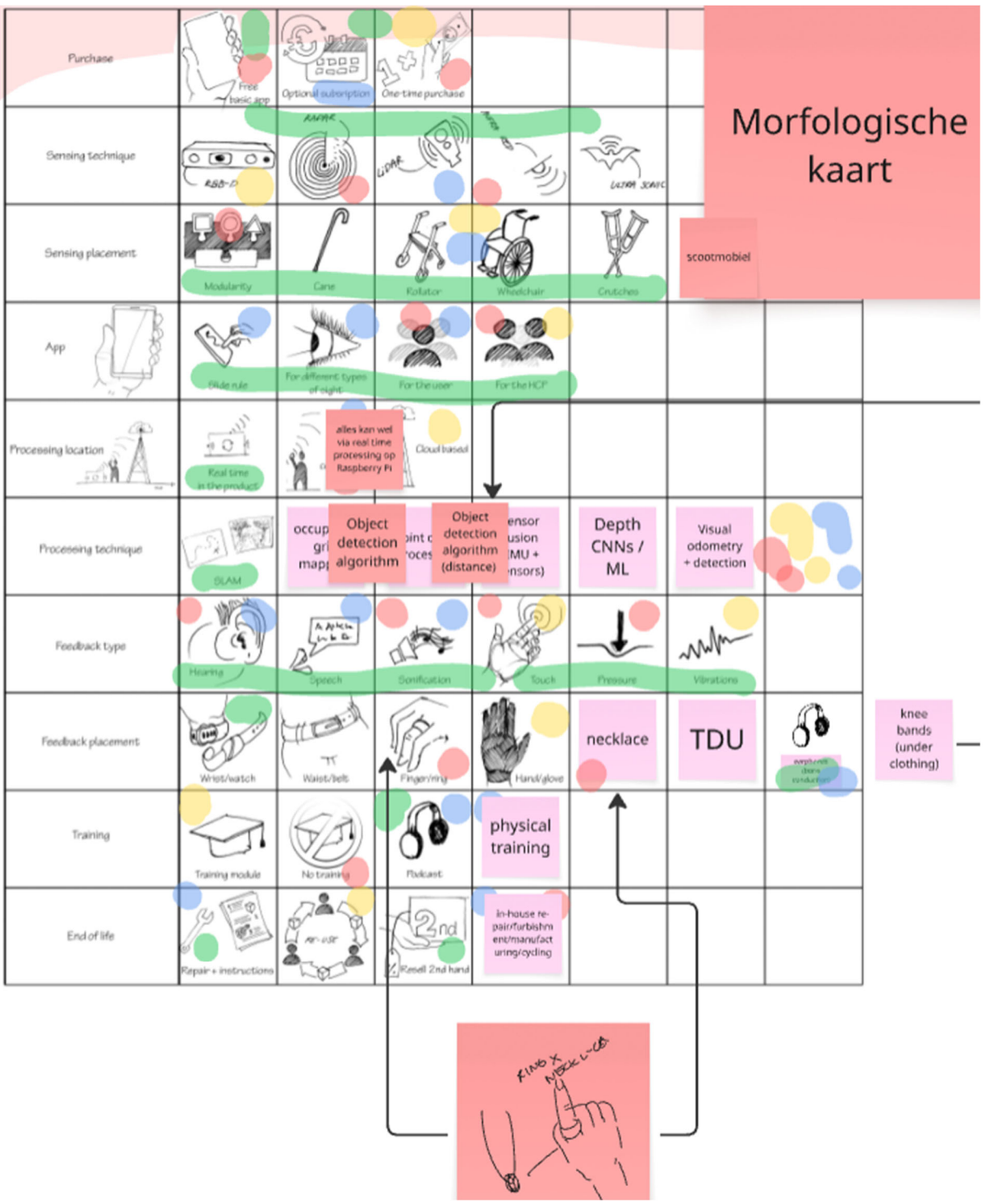
- Pediatric & specialized aids
  - Crocodile walker (reverse walker for kids)

(*R82 Crocodile*, n.d.)

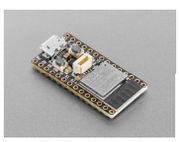
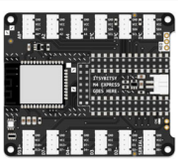
  - Walker with harness / suspension walker

(*Seat Harness for All Wenzelite Safety Rollers and Nimbo Walkers*, n.d.)

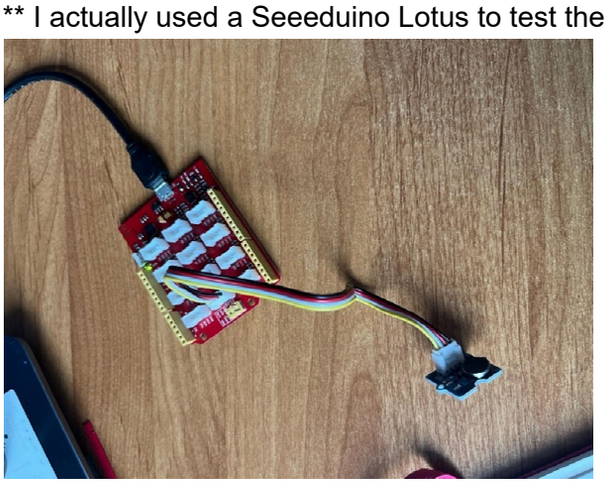
Appendix E: Morphological chart



Appendix F: Wearable prototyping components

Part	Pic	Function	Dimensions	Amount	Price
Itsy bitsy		Communicat e with Raspberry Pi	36.0mm x 17.6mm x 6.9mm	1x	€17,29
Bitsy expander		Enable grove connections to Itsy bitsy	??	1x	€included in IDE prototyping kit
Grove connection cable		connect modules to Bitsy	200 mm	1x (/2x)	€2,36 (5 pack)
Grove Haptic motor		Provide haptic feedback	+/- 20 mm x 20 mm x 10 mm	1x	€2,17
Grove buzzer (optional) or grove speaker		Provide audio feedback	+/- 20 mm x 20 mm x 10 mm	1x	€1,80
USB-A to Micro-B cable		Connect battery to Itsy Bitsy	150 mm	1x	€1,56

** I actually used a Seeeduino Lotus to test the vibration motor.



Appendix G: User validation research

Vibration feedback research

Introduction

One of the goals of this research is that the final product can act as a hands-free substitute of the white cane. To validate this the feedback system has to be tested and compared to the white cane. In this experiment we try to test this to see what the differences are and how the feedback influences people. To test this three (see figure i) obstacle courses were set up each with varying obstacles. The participants will blindly navigate all the different courses with different aids, one being the white cane, and then two sets of different feedback (vibration and audio). For this research we use a vibration collar meant to train dogs to give the feedback to the participants, as the system is not fully developed at the time, the researcher will look closely at the participant and simulate the feedback real time by operating the vibration via the remote.

Research question

"To what extent is vibration feedback on the knees, compared to the white cane, effective in conveying directional and obstacle information for persons with visual impairment?"

Materials

- 2× Sompets® Anti-Bark Collar with Remote Control (No Shock)
- White cane
- Blindfold (for sighted participants) (during this research a Mindfold was used)
- Obstacles (cardboard boxes and water bottles)
- Tape (to fix obstacle positions)
- Tables to fence off courses
- Stopwatch or timer
- Observation form (Appendix I)
- Survey form (Appendix II)
- Informed Consent form (Appendix III)
- Optional: Notepad or digital device for observations

Method:

TBD

Setup:

Three obstacle courses. Boxes taped in random order inside the course. One person operating the feedback devices. One person observing, photographing and taking notes. One survey after the experiment asking about experience of the feedback and comparing the white cane with the vibration device.

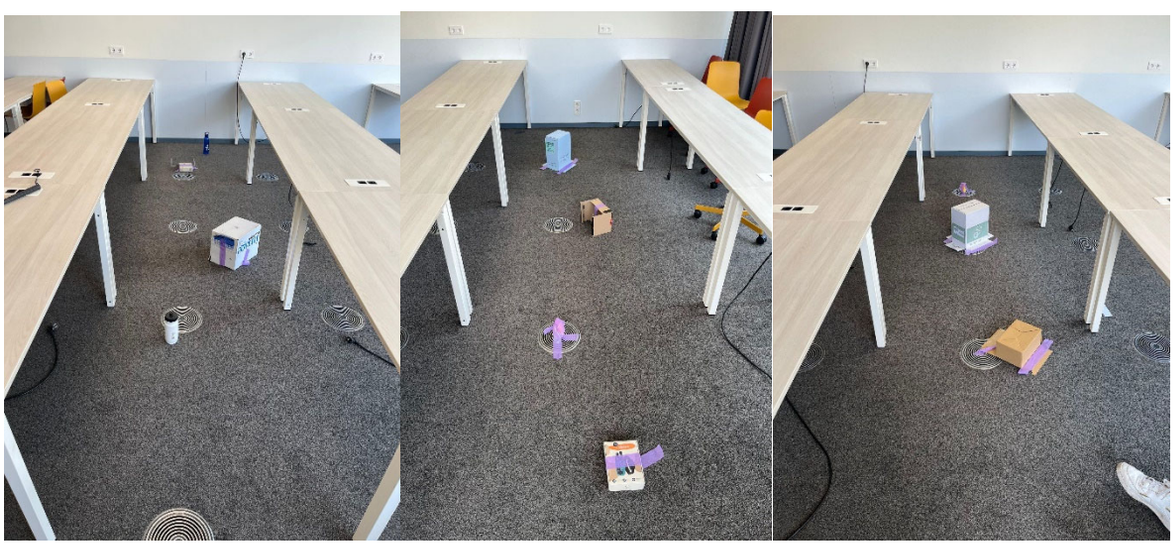


Figure i: Course setup

The survey questions can be found in Appendix II. The measurements done can be found in Appendix I.

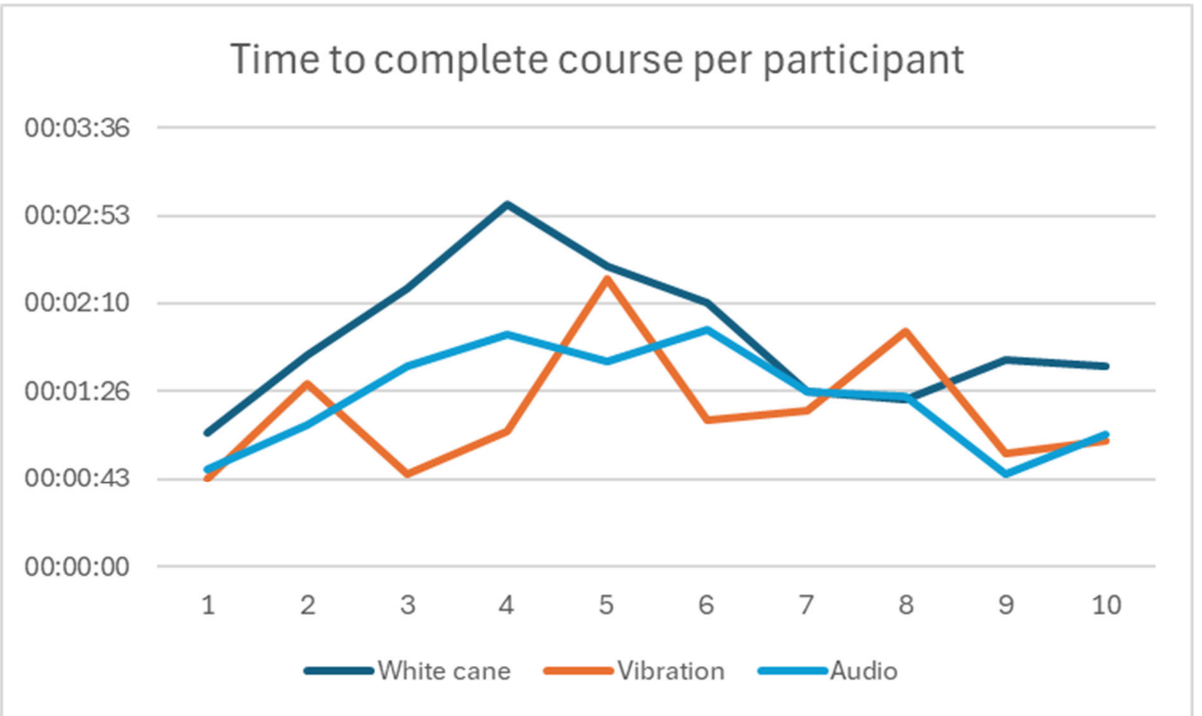
Tasks (3x):

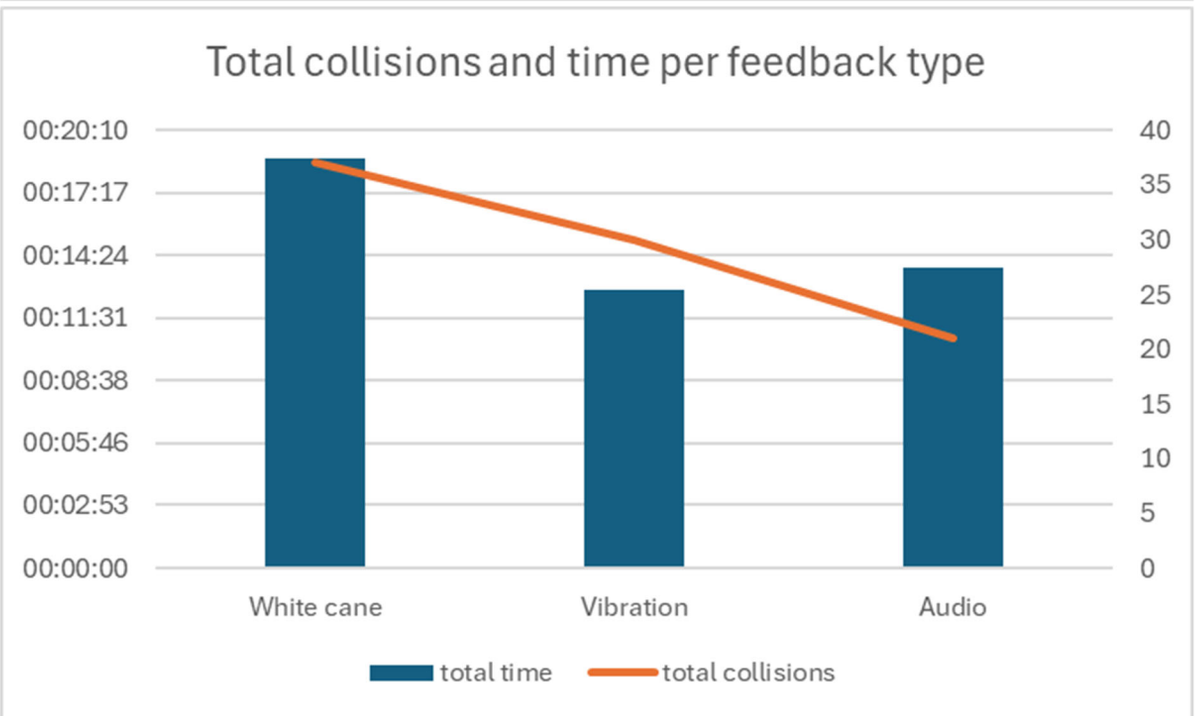
- Walk to the end of the course
- Avoid the obstacles in your way
- Once using a white cane, once using vibration feedback and once using audio feedback

Participants:

- 10 sighted people

Results

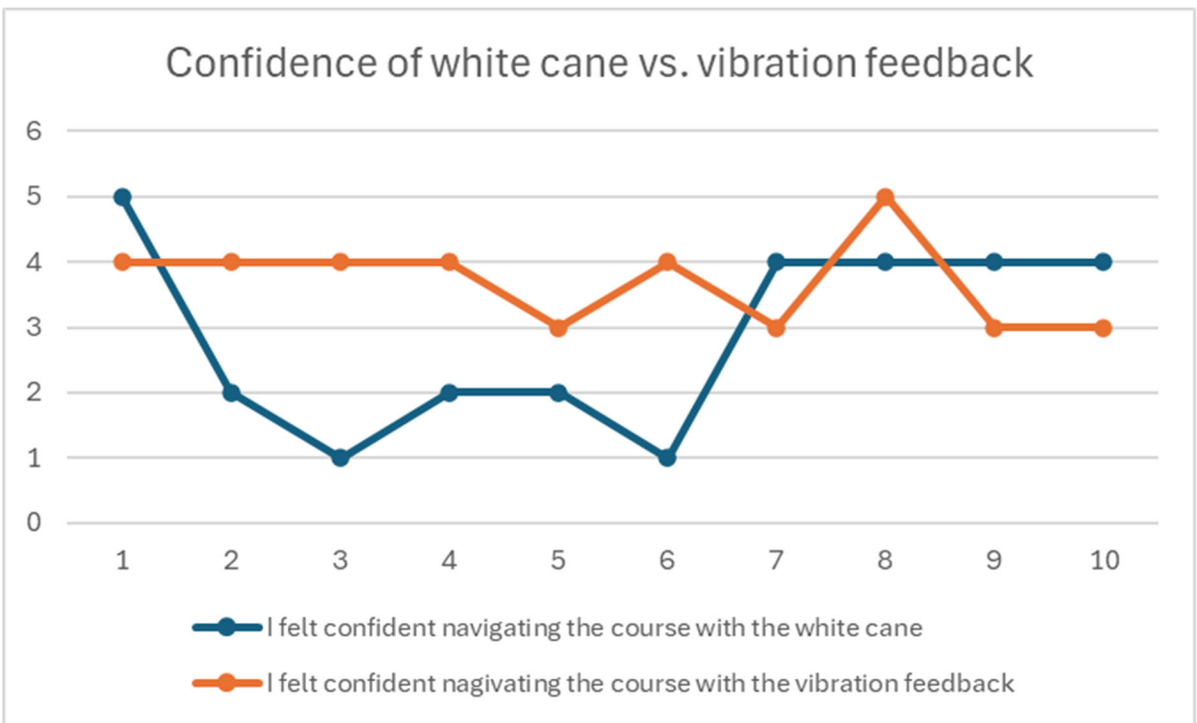


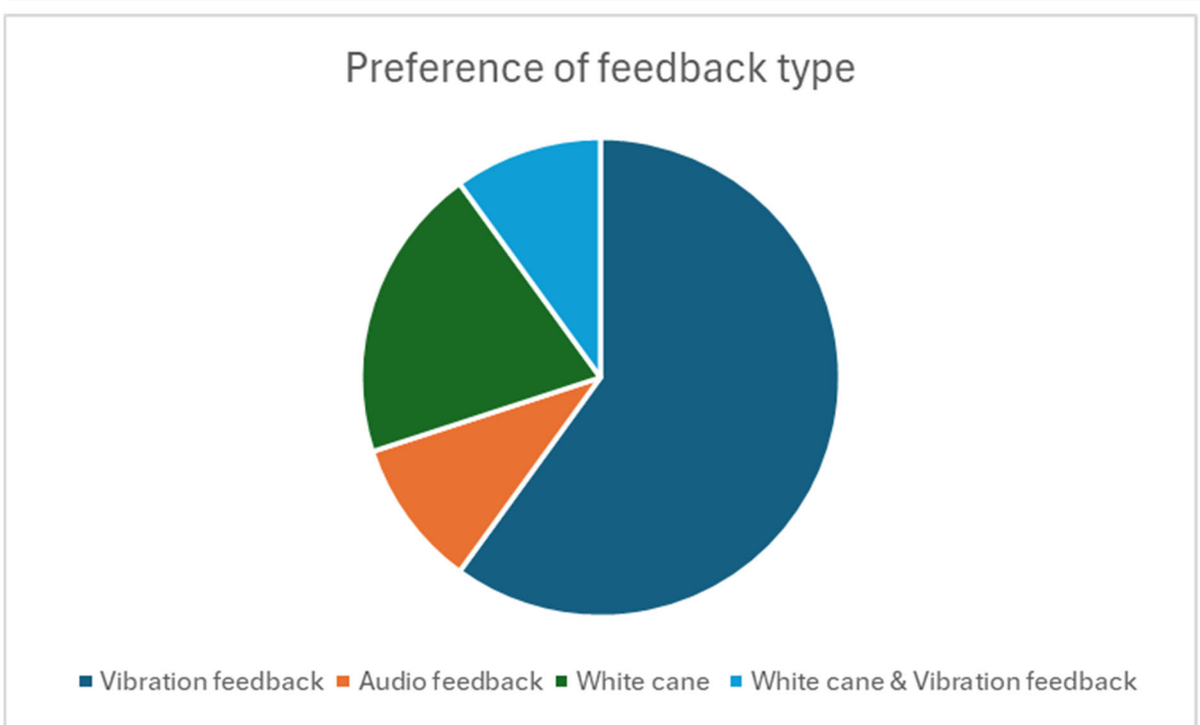


In this chapter some of the results are visualized to find interesting outcomes and see what the answer to the research question could be.

In table FIXME it can be seen that the vibration feedback has a higher confidence score than the white cane.

Participant ID	I felt confident navigating the course with the	I felt confident nagivating the course with the vibration feedback	The vibration feebrack was easy to understand	I was able to react to the vibration feedback in a timely manner	The vibration feedback helped me understand where to go	I felt safe using the vibration feedback system	I would trust a refined version of this system for independent	I think the vibration feedback could substitute a white
1	5	4	4	4	4	4	4	4
2	2	4	4	3	5	4	4	5
3	1	4	5	3	4	4	4	4
4	2	4	4	5	4	5	4	5
5	2	3	4	4	4	3	3	5
6	1	4	5	4	5	4	5	5
7	4	3	4	4	4	3	3	2
8	4	5	5	5	5	5	4	3
9	4	3	3	2	3	3	4	3
10	4	3	3	4	3	3	4	4
Total:	2.9	3.7	4.1	3.8	4.1	3.8	3.9	4





Appendix I - Observation & data collection Form

Observation & Data Collection Form - Vibration Feedback Test

Participant ID: _____

Date: _____

Test Conductor: _____

Observer: _____

Visually Impaired: ☐ Yes ☐ No (blindfolded)

Experience with using a white cane: ☐ Yes ☐ No

---

1. Summary per Condition

Condition	Time (mm:ss)	Number of Collisions	Behavioral Observations (e.g., hesitation, stops, wrong turns)
1. White Cane			
2. Vibration			
3. Feedback with audio			

---

2. Behavioral Checklist (Tick all that apply)

Behavior/Observation	White Cane	Vibration	Audio
Hesitates at start			
Makes abrupt stops			
Misses a clear signal			
Light contact with obstacle			
Strong collision with obstacle			
Takes a wrong direction			
Reacts appropriately to vibration			

Appears confident			
Delayed response to feedback			

3. Additional Notes and Observations

Use this space to record anything notable that occurred during the test session (e.g., issues with vibration system, participant remarks, unusual behavior).

Appendix II - Questionnaire:

Participant Questionnaire – Vibration Feedback Test

Participant ID: _____

Date: _____

Test Conductor: _____

Section 1: Experience and Perception (Likert Scale)

Please indicate your level of agreement with the following statements.

1 = Strongly Disagree | 2 = Disagree | 3 = Neutral | 4 = Agree | 5 = Strongly Agree

Statement	1	2	3	4	5
I felt confident navigating the course with the white cane.	☐	☐	☐	☐	☐
I felt confident navigating the course with the vibration feedback.	☐	☐	☐	☐	☐
The vibration feedback was easy to understand.	☐	☐	☐	☐	☐
I was able to react to the vibration feedback in a timely manner.	☐	☐	☐	☐	☐
The vibration helped me understand where to go.	☐	☐	☐	☐	☐
I felt safe using the vibration feedback system.	☐	☐	☐	☐	☐
I would trust a refined version of this system for independent mobility.	☐	☐	☐	☐	☐
I think the Vibration feedback could substitute a white cane	☐	☐	☐	☐	☐

Section 2: Preference

1. Which of the navigation methods did you prefer overall?
    - ☐ White cane
    - ☐ Vibration feedback
    - ☐ *Feedback with audio
    - ☐ No preference
2. Which of the navigation methods did you find easier to understand?

- ○ ☐ White cane
- ○ ☐ Vibration feedback
- ○ ☐ Feedback with audio
- ○ ☐ No preference

3. With which method did you feel most secure? Why?
4. _____
5. _____
6. _____
7. _____
8. Was the vibration feedback confusing at any point? If yes, please explain.
9. _____
10. _____
11. _____
12. _____
13. What would you change to make the vibration feedback more accurate or helpful?
14. _____
15. _____
16. _____
17. _____
18. Do you believe that vibration feedback (if well-developed) could replace or complement the tactile feedback of a white cane? Why or why not?
19. _____
20. _____
21. _____
22. _____

Section 3: Open Reflection

Please use this space to share any additional thoughts, ideas, or feedback about your experience.

_____

_____

_____

_____

_____

_____

_____

_____

_____

Thank you for your participation!

Appendix III: Informed consent form
Onderzoek: Creating a product-service system for rollator design: a user-centered approach for visually impaired mobility

U wordt uitgenodigd om deel te nemen aan een onderzoek genaamd “Creating a product-service system for rollator design: a user-centered approach for visually impaired mobility”. Dit onderzoek wordt uitgevoerd door Karlijn Borremans van de TU Delft.

Het doel van dit onderzoek is meer te weten te komen over het navigeren van blinden en slechtzienden in het dagelijks leven en zal ongeveer 10-30 minuten in beslag nemen. U zal worden gevraagd verschillende opdrachten te voltooien, waarna u een vragenlijst zal invullen. De data zal gebruikt worden voor het genereren van inzichten en inspiratie voor een uiteindelijk ontwerp, dit ontwerp zal gepubliceerd worden in de TU Delft repository. U wordt gevraagd om vragen te beantwoorden over het leven als blinde of slechtziende.

Zoals bij elke online activiteit is het risico van een data breuk aanwezig. Wij doen ons best om uw antwoorden vertrouwelijk te houden. We minimaliseren de risico’s door de data anoniem te verzamelen en te anonimiseren tenzij u anders aangeeft.

Uw deelname aan dit onderzoek is volledig vrijwillig, en u kunt zich elk moment terugtrekken zonder reden op te geven. U bent vrij om vragen niet te beantwoorden of tijdens het uitvoeren van de gevraagde taken te stoppen. Na verzameling van de data kan deze verwijderd worden, dit zal uiterlijk een maand na het onderzoek worden verwijderd.

Contactgegevens onderzoeker:
Karlijn Borremans
06 31360355

PLEASE TICK THE APPROPRIATE BOXES	Yes	No
A: GENERAL AGREEMENT – RESEARCH GOALS, PARTICIPANT TASKS AND VOLUNTARY PARTICIPATION		
1. Ik heb de informatie over het onderzoek gedateerd *[4/6/2025*] gelezen en begrepen, of deze is aan mij voorgelezen. Ik heb de mogelijkheid gehad om vragen te stellen over het onderzoek en mijn vragen zijn naar tevredenheid beantwoord.	☐	☐
2. Ik doe vrijwillig mee aan dit onderzoek, en ik begrijp dat ik kan weigeren vragen te beantwoorden en mij op elk moment kan terugtrekken uit de studie, zonder een reden op te hoeven geven.	☐	☐
3. Ik begrijp dat mijn deelname aan het onderzoek de volgende punten betekent; - Het geblinddoekt voltooien van 3 obstakel parcours met verschillende manieren van feedback over de obstakels. - Het invullen van een vragenlijst en een eventueel interview over de uitgevoerde taken. - Er zullen foto's genomen worden en observaties worden gemaakt tijdens het uitvoeren van de taken.	☐	☐
4. Ik begrijp dat de studie 11 juli 2025 eindigt.		
B: POTENTIAL RISKS OF PARTICIPATING (INCLUDING DATA PROTECTION)		
5. Ik begrijp dat mijn deelname de volgende risico's met zich meebrengt zoals tegen obstakels aanlopen of struikelen. Ik begrijp dat deze risico's worden geminimaliseerd doordat er iemand aanwezig zal zijn om te voorkomen dat je in gevaar zult komen, verder zullen de objecten niet gevaarlijk zijn om tegenaan te lopen.	☐	☐
6. Ik begrijp dat mijn deelname betekent dat er persoonlijke identificeerbare informatie en onderzoeksdata worden verzameld, met het risico dat ik hieruit geïdentificeerd kan worden.	☐	☐
8. Ik begrijp dat de volgende stappen worden ondernomen om het risico van een data breuk te minimaliseren, en dat mijn identiteit op de volgende manieren wordt beschermd in het geval van een data breuk; - De data zal anoniem worden opgeslagen - De data zal veilig worden opgeslagen met gelimiteerde bevoegdheid - De opnames zullen anoniem worden gepubliceerd en zullen worden verwijderd nadat het onderzoek is afgerond.	☐	☐

10. Ik begrijp dat de persoonlijke informatie die over mij verzameld wordt en mij kan identificeren, zoals naam, woonplaats, niet gedeeld worden buiten het onderzoeksteam.	☐	☐
11. Ik begrijp dat de persoonlijke data die over mij verzameld wordt, vernietigd wordt een maand na het einde van het onderzoek.	☐	☐
C: RESEARCH PUBLICATION, DISSEMINATION AND APPLICATION		
12. Ik begrijp dat na het onderzoek de geanonimiseerde informatie gebruikt zal worden voor een publicatie op de TU Delft repository en mogelijke quotes in deze publicatie.	☐	☐
13. Ik geef toestemming om mijn antwoorden, ideeën of andere bijdragen anoniem te quoten in resulterende producten.	☐	☐
14. Ik geef toestemming om mijn naam te gebruiken voor quotes in resulterende producten .	☐	☐
15. Ik geef toestemming om mijn geanonimiseerde foto’s in de publicatie.		

Signatures

Naam deelnemer	Handtekening	Datum

Ik, **de onderzoeker**, verklaar dat ik de informatie en het instemmingsformulier correct aan de potentiële deelnemer heb voorgelezen en, naar het beste van mijn vermogen, heb verzekerd dat de deelnemer begrijpt waar hij/zij vrijwillig mee instemt.

Naam onderzoeker	Handtekening	Datum

Contactgegevens van de onderzoeker voor verdere informatie: Karlijn Borremans

Appendix H: Electronics testing (sensing module)

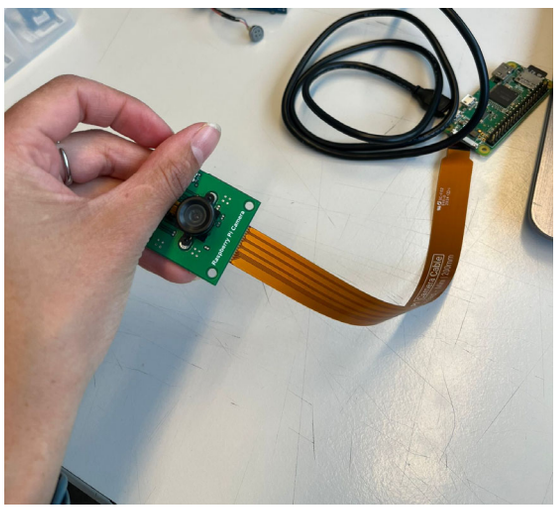
- iteration 1 raspberry pi zero W v1.1
  - This model was too old and not strong enough for the desired scripts to run.
  - Booting this system was already an enormous hassle and resulted in an iteration with a stronger, newer and better equipped model.

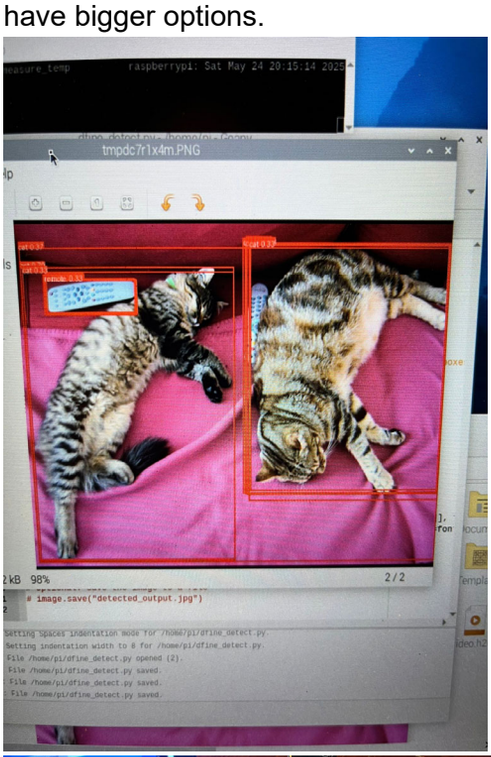
Part	Pic	Function	Dimensions	Amount	Price
Raspberry Pi 4 model B 4gb		Computing, execute script, connect with wearables	85 x 56 mm	1x	€62,3
Micro SD card with reader (with raspberry pi OS 64 bit)		Storage, Contains OS	(goes inside Raspberry Pi)	1x	€9,67
Raspberry Pi Camera	**	Obtain live camera feed	113 x 50 x 24 MM	1x	+/- €18,-
Camera connection cable		Connect Camera to Pi	200 mm long	1x	€1,15
USB-A to USB-C cable		Connect power source to Raspberry Pi	150 mm	1x	€5,80
Powerbank	??	Provide system with energy	??	1x	€??

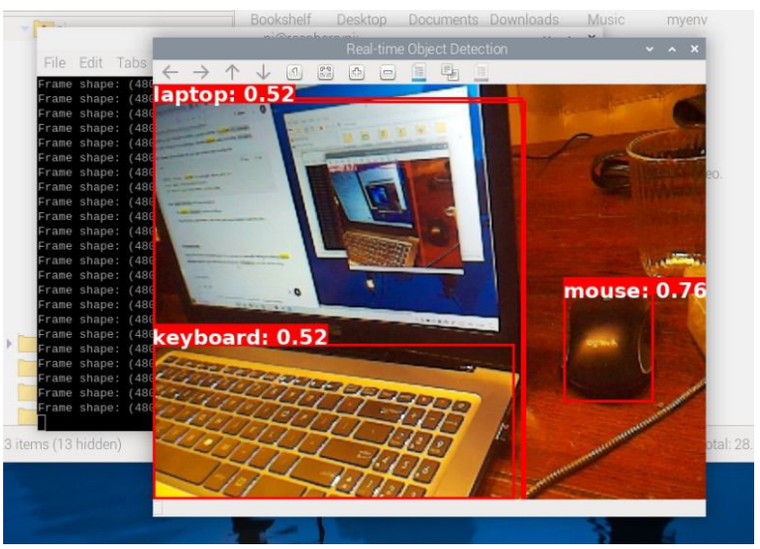
- iteration 2 raspberry pi 4 model B:
  - got the AI script working with this model
  - findings and recommendations:
    - janky feed: should use a specified computer for this, could use raspberry pi 5 with AI top hat (as used by Sam Meech Ward (Sam Meech-Ward, 2024))

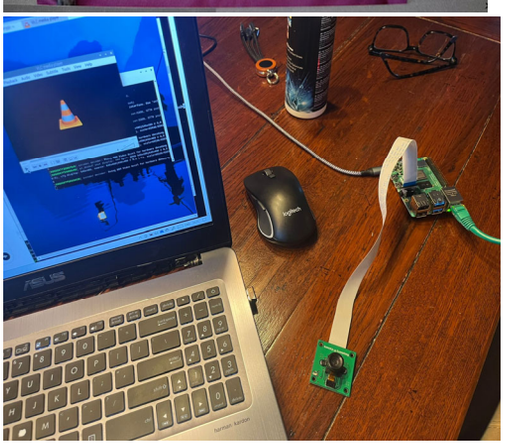
- cooling system: the process is quite heavy on the raspberry pi, it would be better for the durability of the computer and other performance factors to have heat sinks or maybe even active cooling.

The goal of this test was to get an object detection program running on the raspberry pi. To do this I first installed the right libraries for the camera and checked if it was working. After confirming this I had to be able to capture a video feed with the camera, when I was able to get the camera obtain a live feed it was time to start the object detection part. I also again installed the right software for this to be able to detect objects. For this test I used the COCO-nano database (*Ustc-Community/Dfine-Nano-Coco · Hugging Face*, 2025). This database is smaller and will work quicker with my less powerful raspberry pi 4. The COCO database also have bigger options.









Appendix I: Code modules

The code from hugging face (*Ustc-Community/Dfine-Nano-Coco · Hugging Face*, 2025):

```python
import torch
import requests

from PIL import Image
from transformers import DFineForObjectDetection, AutoImageProcessor

url = 'http://images.cocodataset.org/val2017/000000039769.jpg'
image = Image.open(requests.get(url, stream=True).raw)

image_processor = AutoImageProcessor.from_pretrained("ustc-community/dfine-nano-coco")
model = DFineForObjectDetection.from_pretrained("ustc-community/dfine-nano-coco")

inputs = image_processor(images=image, return_tensors="pt")

with torch.no_grad():
    outputs = model(**inputs)

results = image_processor.post_process_object_detection(outputs, target_sizes=torch.tensor([image.size[::-1]]), threshold=0.3)

for result in results:
    for score, label_id, box in zip(result["scores"], result["labels"], result["boxes"]):
        score, label = score.item(), label_id.item()
        box = [round(i, 2) for i in box.tolist()]
        print(f"{model.config.id2label[label]}: {score:.2f} {box}")
```

Figure 87: DFine-Nano-COCO

Appendix J: fasteners research

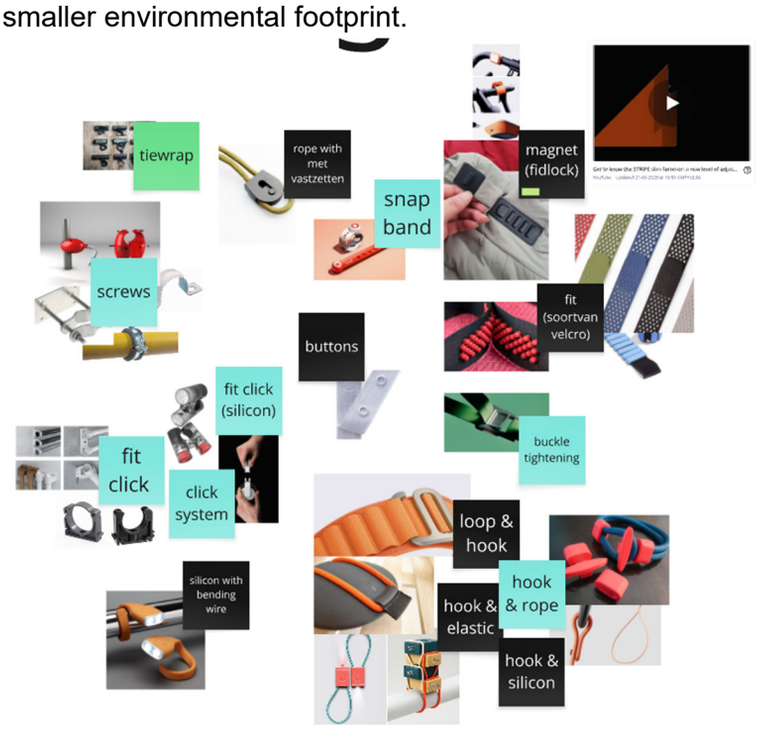
Fastening systems

(See chapter system for an overview of the mobility aids in the scope of this project)

Criterion	Magnetic (Fidlock)	Hook–Loop (Velcro)	Mechanical Clamp (Metal)	Plastic Clip	Elastic (Rubber/Silicone)
Materials	Plastics + NdFeB magnets (rare earth)	Nylon/polyester textile	Steel or aluminum (+ rubber insert)	Engineering plastic	Natural rubber or silicone
Environmental Impact	High (mining/processing rare earth & plastics)	Moderate–high (petro-nylon)	Moderate (mining metals, but recycled)	Moderate (petroleum plastic)	Low-to-moderate (rubber renewable; silicone less)
Durability/Lifespan	Very high (magnets last decades)	High (hundreds–thousands of cycles)	Very high (metal)	Medium (can crack or fatigue)	Medium–high (silicone long, rubber moderate)
Recyclability	Very low (composite item, magnets glued)	Very low (mixed fibers, no local recycling)	High (metals easily recycled)	Low (often not collected)	Rubber – biodegradable; Silicone – not recyclable
Versatility	Limited to specific mounts/range	Very high (adjusts to any size)	Good (adjustable range within design)	Moderate (range-limited)	Very high (stretches to fit many sizes)
Ease of Use	Excellent (intuitive one-hand attach/detach)	Very good (one-hand usable)	Low (requires two-hand tightening)	Fair (varies; often one-hand)	Very good (quick one-hand hook-in)

Overall Impact	Long-lived but high upfront cost (materials)	Reusable but made of plastics; eco-versions exist	Durable and recyclable, but less user-friendly	Lightweight but short-lived and plastic waste	Natural rubber option is renewable/biodegradable; silicone lasts long but is non-biodegradable

Conclusion: Magnetic mounts (Fidlock) shine in ease-of-use and longevity, but use rare-earth materials and plastics that are hard to recyclefidlock.comhir.harvard.edu. Velcro straps strike a balance: they are adaptable and one-hand operablevelcro.com, and when made with recycled or natural fibers (e.g. Velcro's ECO lines) have a reduced footprintvelcro.comcitizensustainable.com. Mechanical clamps (metal) are very durable and recyclable but bulkier and harder to fasten. Plastic clips are the least sustainable due to petroplastics and limited lifespan. **Most sustainable/practical choice:** Hook-and-loop or elastic straps with eco-friendly materials. For example, a Velcro strap made from recycled PET and a natural rubber mount offer good grip, adjustability, and relatively low life-cycle impactvelcro.comrubbercal.com. Elastic silicone bands also score well on ease-of-use and reusability, though they are not biodegradabletreehugger.com. In summary, eco-conscious users should favor recycled-textile straps or natural-rubber loops over pure plastic or magnet-based mounts whenever possible, trading a bit of convenience for a substantially smaller environmental footprint.



Fastening prototyping

- hook and loops
- elastic with button
- clip mechanism
- clamp closure
- bending metal wire

Conclusion

The combination of an elastic (not sure if this is necessary, can also do a hole maybe to loop the strap through) with anti slip and hook and loops presents promising results. This combination is easy to use, modular and reusable.
Kristoff Vaes, stigma driehoek

Scope mobility aids

As this project aims to solve the problem of needing to different types of mobility aids and not having enough hands for this, the product should work on the types of aids that need both hands to use.

Appendix K: Regulatory Compliance Overview

Overview

To ensure the VAMO system is legally marketable and safe for consumers within the European Union, a range of directives and regulations apply. These cover product safety, environmental protection, radio technology, data protection, and general market access. Not all of them fall under CE marking, but compliance with each is legally required.

CE Marking: Product Safety Directives

The **CE mark** is required for most consumer electronics in the EU. For VAMO, the following directives apply:

Directive	Description	Applies to VAMO	Part of CE?
Radio Equipment Directive (2014/53/EU)	Ensures safe and compatible use of wireless technologies like Bluetooth or Wi-Fi	Yes (Bluetooth connection to app)	Yes
Electromagnetic Compatibility Directive (2014/30/EU)	Prevents interference between electronic devices	Yes	Yes
RoHS Directive (2011/65/EU)	Restricts use of hazardous substances in electronics (e.g., lead, mercury)	Yes	Yes
Low Voltage Directive (2014/35/EU)	Applies to electrical products with voltage above 50V AC or 75V DC	Not applicable (VAMO uses low voltage)	Yes
Declaration of Conformity + Technical File	Required documents that prove CE compliance	Yes	Yes

Non-CE but Mandatory EU Regulations

These laws are not part of CE marking but are still **legally required**:

Regulation / Directive	Why It Applies	Applies to VAMO	Part of CE?
General Data Protection Regulation (GDPR)	Required if your product/app collects personal data like location or user profiles	Yes (VAMO app may store user data)	No

Regulation / Directive	Why It Applies	Applies to VAMO	Part of CE?
General Product Safety Directive (2001/95/EC)	Applies to all consumer products to ensure basic safety	Yes	No
Packaging and Packaging Waste Regulation (EU 2025/40)	Requires eco-responsible packaging and labeling	Yes (physical product shipped to user)	No
WEEE Directive (2012/19/EU)	Requires proper disposal/recycling of electronic waste	Yes	No
Battery Regulation (EU 2023/1542)	If VAMO uses batteries, they must be labeled and recyclable	Possibly	No
Cyber Resilience Act (EU 2024/2847)	Applies to digital products with security risk; will be enforced from ~2027	Not yet, but relevant in future	No

What CE Marking Requires in Practice

To meet CE marking requirements, VAMO must:

- Perform **conformity assessments** (lab testing for EMC/RED)
- Create a **technical file** (schematics, risk assessments, user manual, etc.)
- Draft a **Declaration of Conformity (DoC)** signed by the manufacturer
- Affix the **CE mark** to the product, user manual, and packaging

The documentation must be **kept for inspection** but **not submitted** unless requested by authorities.

GDPR Compliance Checklist

Since the VAMO app likely collects user data (e.g. for tracking progress), it must:

- Obtain **explicit user consent** before collecting data
- Provide a clear and accessible **privacy policy**
- Allow users to **delete their data**
- Secure data storage and **limit access**
- Keep track of data flows and access logs

Recommended practice includes **data minimization**: only collect what you truly need.

Future Considerations

If in future VAMO is updated to:

- Detect falls or monitor health,
- Predict injuries based on movement data,
- Include AI-driven diagnostics,

…then it may fall under **Medical Device Regulation (MDR 2017/745)**. This would require:

- Clinical validation
- Registration with a notified body

- Post-market surveillance

Currently, this is **not required**, as VAMO does not make health claims.

Conclusion

While CE marking is your gateway to the EU market, full compliance also includes privacy (GDPR), sustainability (Packaging, WEEE), and consumer safety laws. Following these ensures not only legal compliance but trust, safety, and scalability, especially for a vulnerable group like MVIPs.

Appendix L: Cost Estimation Details

This appendix outlines the full calculation of the production costs for the VAMO system. The cost per unit consists of the fixed costs for tooling (divided over all units), the price of all electronic and mechanical components, and additional operational costs for assembly, packaging, and transport.

Tooling and Moulding Costs

Injection moulds are needed to produce:
- The plastic housing of the sensing module
- The mechanical ball and connection element
- The two wearable plastic housings
- Two silicone wristbands

The estimated total investment for all required moulds is €70,000. This cost is divided over the number of units produced.
Tooling cost per unit:
Pessimistic: €70.00
Estimated: €14.00
Optimistic: €3.50
Plastic part costs per set:
- Sensing module housing: €0.25
- Ball and connection piece: €0.25
- Wearable housings (2×): €0.40
- Silicone wristbands (2×): €1.20

Electronics and Mechanical Components

The electronics and mechanical components needed per VAMO system are:
- Custom PCBs (main + 2× wearable): €22.00
- Bluetooth modules (2×): €4.70
- Micro LiDAR sensor: €22.20
- Vibration motors (2×): €2.00
- Batteries (1 medium + 2 small Li-Po): €6.00
- Camera module (Pi Camera Module 3 Wide): €18.00
Total component cost (no discount): €74.90
Component cost per scenario:
- Pessimistic: €74.90
- Estimated: €60.00
- Optimistic: €37.00

Operational Costs

Assembly (manual): €1.00
Packaging (shared box): €0.12
Transport and logistics: €1.50
Total operational cost per unit: €2.62

Total Unit Cost Calculation

Pessimistic: €147.50
Estimated: €76.60
Optimistic: €43.10

Sales Price Estimation

A markup of approximately 3× is applied to cover:
- App development and maintenance
- Certification and testing
- Customer service and warranty
- Distribution and margins

Sales price per scenario:
- Pessimistic: €449
- Estimated: €245
- Optimistic: €129

References

1. Fanstel Bluetooth Modules – https://www.fanstel.com
2. TF-Luna LiDAR – https://www.robotshop.com
3. ERM Coin Vibration Motors – https://www.precisionmicrodrives.com
4. Li-Po batteries – https://www.batteryspace.com / https://www.alibaba.com
5. Raspberry Pi Camera – https://www.raspberrypi.com/products/camera-module-3-wide/
6. Packaging carton – https://telecajas.com/en/products/cardboard-moving-box-60x40x40-cm
7. PCB quotes – https://jlcpcb.com / https://pcbway.com

Appendix N: Project brief

7540

TU Delft

DESIGN FOR our future

IDE Master Graduation Project

Project team, procedural checks and Personal Project Brief

In this document the agreements made between student and supervisory team about the student's IDE Master Graduation Project are set out. This document may also include involvement of an external client, however does not cover any legal matters student and client (might) agree upon. Next to that, this document facilitates the required procedural checks:

- Student defines the team, what the student is going to do/deliver and how that will come about
- Chair of the supervisory team signs, to formally approve the project's setup / Project brief
- SSC E&SA (Shared Service Centre, Education & Student Affairs) report on the student's registration and study progress
- IDE's Board of Examiners confirms the proposed supervisory team on their eligibility, and whether the student is allowed to start the Graduation Project

STUDENT DATA & MASTER PROGRAMME
Complete all fields and indicate which master(s) you are in

Family name	Borremans
Initials	K.R.I.
Given name	Karlijn
Student number	

IDE master(s) IPD ✔ Dfl ☐ SPD ☐

2nd non-IDE master

Individual programme *(date of approval)*

Medisign ☐

HPM ☐

SUPERVISORY TEAM
Fill in he required information of supervisory team members. If applicable, company mentor is added as 2nd mentor

Chair	Jan Willem Hoftijzer	dept./section	HF, HCD
mentor	Vince Vijsma	dept./section	HTR, HCD
2nd mentor			
city:	Delft	country:	The Netherlands
optional comments			

! Ensure a heterogeneous team. In case you wish to include team members from the same section, explain why.

! Chair should request the IDE Board of Examiners for approval when a non-IDE mentor is proposed. Include CV and motivation letter.

! 2nd mentor only applies when a client is involved.

APPROVAL OF CHAIR on PROJECT PROPOSAL / PROJECT BRIEF -> to be filled in **by the Chair** of the supervisory team

Sign for approval (Chair)

Name	Date	Signature
J.W. HOFTIJZER	17-2'2025	

CHECK ON STUDY PROGRESS

To be filled in **by SSC E&SA** (Shared Service Centre, Education & Student Affairs), after approval of the project brief by the chair. The study progress will be checked for a 2nd time just before the green light meeting.

Master electives no. of EC accumulated in total _____ EC

Of which, taking conditional requirements into account, can be part of the exam programme _____ EC

X	**YES**	all 1st year master courses passed
	NO	missing 1st year courses

Comments:

Sign for approval (SSC E&SA)

Name Lisette Boot Date 19-02-2025 Signature

APPROVAL OF BOARD OF EXAMINERS IDE on SUPERVISORY TEAM -> to be checked and filled in by IDE's Board of Examiners

Does the composition of the Supervisory Team comply with regulations?

YES	V	Supervisory Team approved
NO		Supervisory Team not approved

Comments:

Based on study progress, students is ...

V	**ALLOWED** to start the graduation project
	NOT allowed to start the graduation project

Comments:

Sign for approval (BoEx)

Name Monique von Morgen Date 25/2/2025 Signature

DESIGN FOR our future

TUDelft

Personal Project Brief – IDE Master Graduation Project

Name student Karlijn Borremans **Student number**

PROJECT TITLE, INTRODUCTION, PROBLEM DEFINITION and ASSIGNMENT

Complete all fields, keep information clear, specific and concise

Project title Creating a product-service system for rollator design: a user-centered approach for visually impaired mobility

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

Introduction

Describe the context of your project here; What is the domain in which your project takes place? Who are the main stakeholders and what interests are at stake? Describe the opportunities (and limitations) in this domain to better serve the stakeholder interests. (max 250 words)

Context/Domain:
Mobility is a significant challenge for individuals who are both visually impaired and have additional mobility restrictions. Navigating daily life independently can be difficult, requiring innovative solutions to enhance safety, awareness, and confidence in movement.
Stakeholders:
The key stakeholders include visually impaired individuals, their caregivers or physiotherapists, and , the manufacturer of the rollator. Each stakeholder has a significant interest in improving mobility solutions; users seek enhanced independence and safety, caregivers and physiotherapists require effective assistive tools, and aims to innovate in the mobility aid sector.
This project focuses on individuals who are completely blind, ensuring that the solution addresses the most significant mobility challenges. By prioritizing their needs, the design will likely benefit the full spectrum of visually impaired users. Since blind individuals have the greatest reliance on assistive technologies for navigation, they will likely have a lower threshold for adopting a well-designed solution, making it a more attractive and valuable mobility aid.
Opportunities and challenges:
The integration of feedback technology into mobility aids presents both opportunities and challenges. Feedback has the potential to significantly improve user experience by offering real-time, tactile guidance. However, ensuring intuitive and non-intrusive feedback, ergonomic comfort, and seamless integration with existing mobility aids poses technical and design constraints.

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introduction (continued): space for images

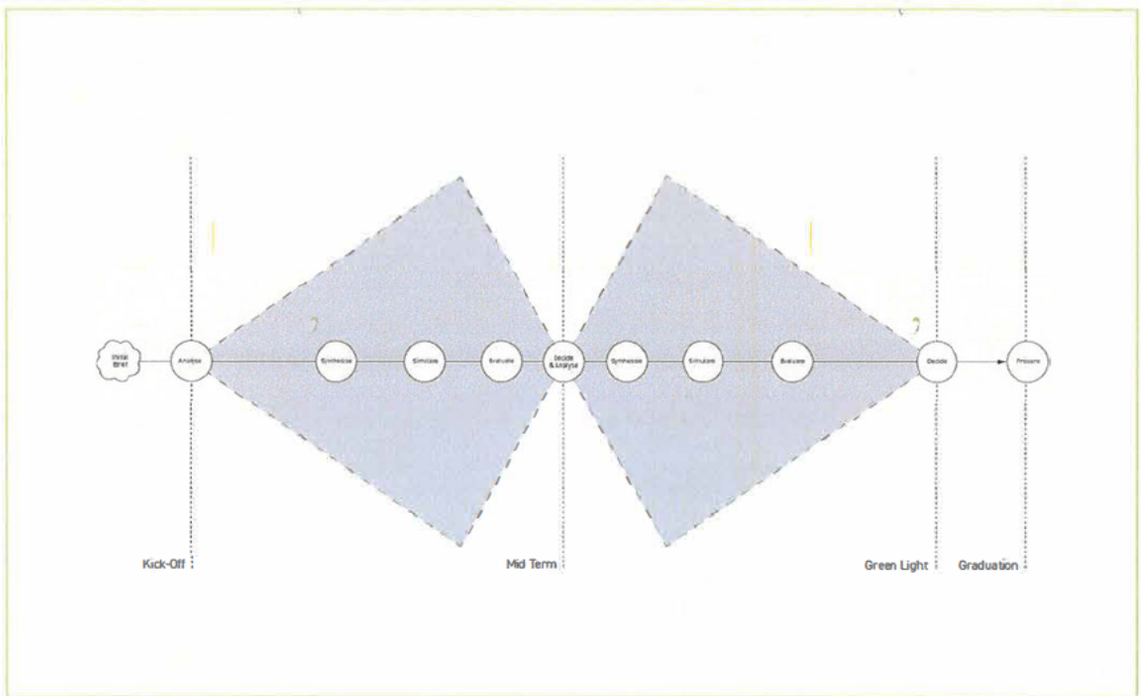


image / figure 1 General project approach

image / figure 2

DESIGN FOR our future

TU Delft

Personal Project Brief – IDE Master Graduation Project

Problem Definition

What problem do you want to solve in the context described in the introduction, and within the available time frame of 100 working days? (= Master Graduation Project of 30 EC). What opportunities do you see to create added value for the described stakeholders? Substantiate your choice.
(max 200 words)

Problem statement:
Visually impaired individuals, especially those who are completely blind, face a paradox when it comes to mobility aids: they cannot effectively use a white cane while also operating a rollator, yet they may be unable to walk safely without one. Guide dogs offer an alternative, but they are expensive and not accessible to everyone. As a result, visually impaired people may struggle to find a mobility solution that provides both support and environmental awareness, limiting their independence and safety.
Opportunities:
This project aims to bridge that gap by enhancing the functionality of a rollator with sensory feedback, allowing visually impaired users to receive real-time navigation and obstacle information without relying on additional mobility aids. By integrating this technology, the rollator becomes a more viable and attractive option, reducing the barriers to adoption and increasing mobility opportunities.
Added value stakeholders: Users gain greater independence and safety, caregivers experience reduced concerns about safety, physiotherapists can recommend a more adaptive mobility aid, and strengthens its position as an innovator in assistive devices. Addressing this issue within the given timeframe will focus on confirming proof of concept, safety, accurately conveying feedback and concept sketches.

Assignment

This is the most important part of the project brief because it will give a clear direction of what you are heading for. Formulate an assignment to yourself regarding what you expect to deliver as result at the end of your project. (1 sentence) As you graduate as an industrial design engineer, your assignment will start with a verb (Design/Investigate/Validate/Create), and you may use the green text format:

Create a product service system for mobility aids to improve independent mobility and safety for visually impaired users in daily life.

Then explain your project approach to carrying out your graduation project and what research and design methods you plan to use to generate your design solution (max 150 words)

The project will follow the Double Diamond method, with two Basic Design Cycle iterations. The first cycle will focus on research, concept development, and defining design requirements, while the second will emphasize refinement, prototyping, and validation.
First phase:
In the first phase, I will conduct desktop research (literature review, market analysis) and stakeholder interviews to identify user needs. I will also analyze existing walkers/rollators and map the customer journey, synthesizing insights into design requirements. This phase includes early concept generation, leading to several design directions. At the midterm evaluation, I will select the most promising concept for further development.
Second phase:
The second phase, will be another design cycle, this starts with refining the starting values.This phase focuses on prototyping, testing, and validation, ensuring the design meets usability, safety, and feedback effectiveness goals.
Meetings:
I will hold weekly meetings with my company mentor and academic supervisors to ensure alignment.

Project planning and key moments

*To make visible how you plan to spend your time, you must make a planning for the full project. You are advised to use a Gantt chart format to show the different phases of your project, deliverables you have in mind, meetings and in-between deadlines. Keep in mind that all activities should fit within the given run time of 100 working days. Your planning should include a **kick-off meeting**, **mid-term evaluation meeting**, **green light meeting** and **graduation ceremony**. 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 course activities).*

Make sure to attach the full plan to this project brief.
The four key moment dates must be filled in below

Kick off meeting	11 Feb 2025
Mid-term evaluation	8 Apr 2025
Green light meeting	13 Jun 2025
Graduation ceremony	11 Jul 2025

In exceptional cases (part of) the Graduation Project may need to be scheduled part-time. Indicate here if such applies to your project

Part of project scheduled part-time	
For how many project weeks	
Number of project days per week	

Comments:

Motivation and personal ambitions

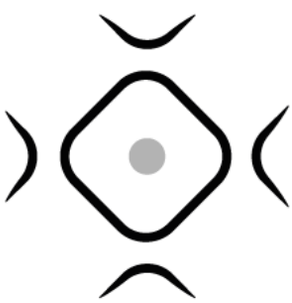
Explain why you wish to start this project, what competencies you want to prove or develop (e.g. competencies acquired in your MSc programme, electives, extra-curricular activities or other).

Optionally, describe whether you have some personal learning ambitions which you explicitly want to address in this project, on top of the learning objectives of the Graduation Project itself. You might think of e.g. acquiring in depth knowledge on a specific subject, broadening your competencies or experimenting with a specific tool or methodology. Personal learning ambitions are limited to a maximum number of five.
(200 words max)

Motivation:
During my internship, I realized how important it is for me to create meaningful impact through design. I sought a project that aligns with this ambition, leading me to this challenge: improving mobility for visually impaired individuals with limited physical abilities, a vulnerable group that is often overlooked. As someone with a mild visual impairment, I can only imagine how frustrating it must be to lose the ability to walk independently after having mastered existing mobility techniques for the visually impaired. This motivates me to thoroughly understand the problem and contribute to a well-designed solution.
Ambitions:
From my internship feedback, I was adviced to gain more experience in project management. Through this project, I want to improve my ability to plan effectively, recognize when a design is "good enough," and stay focused on what is within scope.

Additionally, I aim to develop my skills in app prototyping (e.g., Adobe XD, Figma) by designing an accessible interface for blind users or caregivers.

Lastly, I want to enhance my visual communication skills, ensuring that my sketches, design iterations, and final report are both clear and aesthetically compelling throughout the project.



Graduate student
K.R.I. Borremans (Karlijn)
Industrial Design Engineer

Supervisory team
Chair: Dr. Ir. J.W. Hoftijzer (Jan Willem)
Mentor: V. Vijsma BA (Vincent-André)