**TALLINN UNIVERSITY OF TECHNOLOGY**
SCHOOL OF ENGINEERING
Department of Mechanical and Industrial Engineering

**ESTONIAN ACADEMY OF ARTS**
FACULTY OF DESIGN

**MSc. Design and Technology Futures**

# HOW TO SHARE SIDEWALKS WITH AUTONOMOUS ROBOTS?

## KUIDAS JAGADA KÕNNITEID AUTONOOMSETE ROBOTITEGA?

MASTER THESIS

Student: Maria Maasikamäe

Student code: 212026MADM

Supervisor: Janno Nõu

Tallinn 2024

# AUTHOR’S DECLARATION

Hereby I, Maria Maasikamäe, declare that I have written this thesis independently. No academic degree has been applied for based on this material. All works, major viewpoints and data of the other authors used in this thesis have been referenced.

“.......” .................... 202…..

Author: ..............................
/signature /

Thesis is in accordance with terms and requirements “.......” .................... 202….

Supervisor: ….........................
/signature/

Accepted for defence “.......”....................202… .

Chairman of theses defence commission: .........................................................
/name and signature/

# Non-exclusive licence for reproduction and publication of a graduation thesis[1]

I, Maria Maasikamäe, grant Tallinn University of Technology (TalTech) and Estonian Academy of Arts (EKA) a non-exclusive licence for my thesis

**How to Share Sidewalks With Autonomous Robots?**

Kuidas jagada kõnniteid autonoomsete robotitega?

Supervised by **Janno Nõu**

1.1 to be reproduced for the purposes of preservation and electronic publication of the graduation thesis, incl. to be entered in the digital collection of the library of Tallinn University of Technology until expiry of the term of copyright;

1.2 to be published via the web of Tallinn University of Technology, incl. to be entered in the digital collection of the library of Tallinn University of Technology until expiry of the term of copyright.

1. I am aware that the author also retains the rights specified in clause 1 of the non exclusive licence.

2. I confirm that granting the non-exclusive licence does not infringe other persons' intellectual property rights, the rights arising from the Personal Data Protection Act or rights arising from other legislation.

______________ (date)

---

[1] The non-exclusive licence is not valid during the validity of access restriction indicated in the student's application for restriction on access to the graduation thesis that has been signed by the school's dean, except in case of the university's right to reproduce the thesis for preservation purposes only. If a graduation thesis is based on the joint creative activity of two or more persons and the co-author(s) has/have not granted, by the set deadline, the student defending his/her graduation thesis consent to reproduce and publish the graduation thesis in compliance with clauses 1.1 and 1.2 of the non-exclusive licence, the non-exclusive licence shall not be valid forthe period.

## Department of Mechanical and Industrial Engineering
# THESIS TASK

**Student** : Maria Maasikamäe 212026MADM
Study programme, Design and Technology Futures
Supervisor: Janno Nõu, (+372) 5649 1761

**Thesis topic**:
How to Share Sidewalks With Autonomous Robots?

Kuidas jagada kõnniteid autonoomsete robotitega?

**Thesis main objectives**:

1. Research the factors influencing the experience of using sidewalks.
2. Identify potential problem areas and opportunities to enhance the interaction experience between the humans and sidewalk robots.
3. Explore ways to improve the predictability of sidewalk robots and propose potential design elements.

**Thesis tasks and time schedule:**

| No | Task description | Deadline |
|---|---|---|
| 1. | Problem Statement Formulation | 15 February 2024 |
| 2. | Initial Design Concept | 21 March 2024 |
| 3. | Concept Exploration | 18 April 2024 |
| 4. | Prototyping and Testing | 27 April 2024 |
| 5. | Evaluation and Conclusion | 2 May 2024 |
| 6. | Thesis Finalization | 20 May 2024 |

**Language:** English **Deadline for submission of thesis:** 20 May 2024

**Student:** Maria Maasikamäe ......................... “........” ............... 20......

*/signature/*

**Supervisor:** Janno Nõu ......................... “........” ............... 20......

*/signature/*

**Head of study programme:** Kätlin Kangur......................... “........” ............... 20......

*/signature/*

*Terms of thesis closed defence and/or restricted access conditions to be formulated on the reverse side*

# ABSTRACT

Cities have become the primary habitat for humans, shaping the way we live, work, and move. Alongside the growing population of cities, the number of people using sidewalks is also increasing. Walking and other forms of active transport, commonly performed on sidewalks, offer numerous health benefits, promoting physical fitness and reducing the risk of chronic diseases. However, the urban landscape is continuously evolving, introducing new elements such as e-scooters and autonomous sidewalk robots (ASRs) to our sidewalks.

While the introduction of such robots has generally been accepted by communities, it has not been entirely smooth. The interaction between human sidewalk users and autonomous robots presents certain challenges rooted in the robots' social behaviour, deviating from that of humans, compounded by deficits in interaction features to clearly communicate their intentions. These factors often lead to misunderstandings between robots and humans, potentially resulting in dangerous situations.

This study explores the interaction design of autonomous sidewalk robots to improve their predictability among human sidewalk users. Through iterative phases of prototyping, user feedback, and real-life experimentation, the aim is to identify design elements that enhance the clarity of ASR intentions. The scope of this thesis is to propose and test individual elements of interaction, as well as combinations thereof.

Findings suggest that specific visual and auditory cues, along with movement patterns, can potentially improve pedestrian understanding and safety in interactions with ASRs. The practical research proposes which elements and combinations have the most potential to improve predictability and how to implement them on Starship Delivery robots.

# PREFACE

To tell the whole story honestly, I have to start with the fact that I have been working as a delivery robot tester at Starship [1] for almost 7 years now. This means I've spent thousands of hours watching how my fleet of robots roams the streets of Tallinn and abroad. When I call them "my fleet," I must admit I'm emotionally attached, and I attribute to them human qualities, character, and free will. It's not uncommon to feel attached to the robots you work with, though. I happened to read that military personnel who work with bomb disposal robots feel a range of emotions, such as frustration, anger, and even sadness, when their field robot is destroyed [2]. Similarly, I was sincerely sad when my favourite robot, 6E24, was taken from my fleet to be sent to the US to deliver food at the James Madison University campus. I still think about it sometimes.

In everyday life, anthropomorphisation of the robots I work with leads to treating them slightly like pets, patting them on their bums, and encouraging them with "go on now." But sometimes, when they do not behave well, I get frustrated and exclaim, "Why did you do that?!" Actually, I am well aware that robots do what they do based on the software I have just installed on them, taking into account their hardware limitations.

During their everyday duties the Starship robots have encountered millions of human-beings, and each encounter is an interaction of a sort. Perhaps the most common interaction mirrors that of humans navigating the streets – a mutual decision on which direction to pass each other. As delivery robots become a novel addition to the cityscape, it's natural that the interaction between them and humans is not fully established yet. Witnessing a plastic box on wheels navigating the city naturally sparks questions, arouses curiosity, and prompts cautiousness among people. As delivery robots continue their development journey, their hardware and software currently impose limitations on their social skills, which are yet to be refined.

My eternal question, "Why did you do that?" is something I often ponder while observing them roam around. After philosophising over the question, often with my morning cocoa in hand, I've come to the conclusion that our otherwise cute and harmless robots fundamentally lack some social skills which root in deviation from human social behaviour.

As those robots are made of plain plastic, they lack the mimics, gestures, and body language that humans use while communicating with each other. The absence of these features makes it harder to understand their intentions. For instance, encountering a robot standing still on a snowy sidewalk can leave curious or worried humans confused about how to interpret the situation. Typically, a concerned individual will pause, observe the robot from a relative distance, and then approach for a closer inspection. At times, they may attempt to assist the robot, particularly if it appears stuck in the snow. However, the robot remains expressionless, providing no indication of whether it requires assistance or not.

When I began to wonder why these interaction errors occur, I also started observing how humans walk on streets and why they do not encounter as many issues. This led to the understanding that humans use and interpret quite direct but subconscious body language. For instance, when a human intends to turn left or enter a building on the left-hand side, they start drifting towards the left side of the sidewalk well before the actual manoeuvre takes place. Other pedestrians interpret this as an indication of the intent to turn left and adjust their paths accordingly.

In both human and animal behaviour, encountering strangers often involves adjusting one's path to smoothly navigate around them, avoiding direct approaches. As a dog owner, I know that, in dogs' social interactions, a direct approach is seen as threatening. Similarly, in human social interactions, it's considered rude to invade personal space. However, the robots I work with occasionally disregard this unwritten rule, approaching pedestrians without adjusting their trajectory and forcing them to step aside. Other annoying behaviours I've observed include frequent instances where a robot abruptly turns 90 degrees as a human passes by, cutting off their path. Abrupt and unpredictable maneuvers also include, in addition to turning, sudden stopping and starting driving without any sign whatsoever that they intend to do so.

Although philosophising and analysing an issue is mentally stimulating, as a hands-on person, it led me to consider how to solve the previously mentioned problems. This research represents an attempt to explore human-delivery robot interaction and test out some ideas simultaneously. Much of the practical research is conducted “on the go,” with an effort to remain systematic and avoid getting lost in the process.

As Starship’s customers show their appreciation by sending fan mail back with the robots, I want to include my own fan mail here to all those who have supported me throughout the journey of completing this thesis. I couldn't have pulled it off solo!

First, I want to thank my fantastic supervisor, Janno, who gave me enough freedom but provided comprehensive feedback and guidance throughout the process. I truly enjoyed our discussions! I also want to thank Martin and Kätlin for giving feedback, asking the right questions, and helping to formulate all my ideas and perspectives into a unified whole.

I owe a debt of gratitude to Anti from Starship, who, as a mentor, encouraged me to work on the topic despite my initial hesitations. Our conversations opened a whole new viewpoint for me. I'd like to extend my appreciation also to Anna from Starship for her valuable insights into conflict situations between humans and robots. I’m deeply grateful to my awesome team, Leela and Madis, for supporting me throughout my studies and providing time to work on my thesis.

My brother Martin, who helped out with powering the prototype, yet again, saved my electronic endeavours. Can’t thank you enough! Huge thanks are going to Piret and Joan for lending their hands and a drone for testing the prototype in public. It was great fun working with you!

Last but certainly not least, my deepest and most heartfelt gratitude goes to Sten for proposing solutions in an unsolvable situation, spending a Sunday taping foil and cardboard, and for his efforts in filming and editing. You've bailed me out so many times!

# TABLE OF CONTENT

# 1 INTRODUCTION

The city is now officially the main habitat of *Homo sapiens* [3]. Today, 55% of the world's population lives in urban areas, a proportion that is expected to increase to 68% by 2050 [4]. Even though cities appear to grow 'naturally' according to specific scaling laws, intervention and planning are needed to protect the health of the residents and to limit the environmental impact of cities [3]. Walking and active transport are widely recognised as the most accessible way to achieve the 5 hours of physical activity per week recommended by the World Health Organisation [5].

The growing population presents us with a set of challenges. Specifically, the limited space in cities leads to conflicts of interest regarding how to allocate space for mobility. Road users have different needs that must be addressed. Biases in how these needs are prioritised, both by the public and governments, have resulted in disproportionately less space being assigned to pedestrians and micromobility users [6] while roads are congested by motorists.

Yet another aspect connected to mobility challenges is the changed lifestyle enabled by the technological revolution of Information and Telecommunication Technologies [7]. Rapidly growing e-commerce, on the one hand, provides us with 24/7 access to goods and services, but on the other, contributes to increasing traffic volumes [8]. Tech companies have reacted to these mobility challenges by providing solutions using autonomous robots that operate on sidewalks to deliver goods. As the phenomenon of autonomous delivery robots is novel, the complex environment of sidewalks has presented companies with many problems that need to be solved.

The most crucial challenge influencing human sidewalk users is the interaction between humans and robots. Researchers have identified many problem areas connected to the safety and overall sense-making of the robots. Humans use social cues [9] and behavioural alignment [10] to interact and react to other humans on sidewalks. However, this dynamic does not work as effectively between ASRs and humans.

Emphasising the complex and intertwined problem set of communication between humans and sidewalk robots, the constructive design research of this thesis explores opportunities to improve sidewalk robots' predictability through enhancements in interaction design. The focal point of the research is manoeuvring, as movement and changes in speed and direction pose the greatest risks of accidents. While robots are often perceived as cute and likeable, research by various authors indicates that their behaviour can be unpredictable and divergent from human norms. To protect our cityscapes and ensure safe sidewalks, these shortcomings in robot behavior need to be addressed, leading to the research question: "How to improve autonomous sidewalk robot's predictability among sidewalk users?"

"This exploration contributes to the domain by employing a practical approach of prototyping and testing various interaction elements. As a result, it is proposed which individual interaction elements and their combination have the potential to improve overall predictability of sidewalk robots.

## 1.1 Limitations of Study

In the complex environment of sidewalks, everything is interconnected. However, within the scope of this research, only the potential of individual interaction elements and their combinations is evaluated. Longitudinal testing and data gathering about the impact of these individual elements and their combinations are not conducted within this scope. Such testing needs to be conducted to evaluate their impact effectively.

**Location:** The testing is conducted in Tallinn, Estonia. It's important to note that sidewalk robots have been present on the streets of Tallinn since 2015 [1]. This research does not explore how a human sidewalk user reacts to encountering a sidewalk robot for the first time. Instead, it focuses on the reactions of pedestrians and micromobility users who are already accustomed to the robots, observing how they respond to the robots indicating their intention to perform a maneuver.

# 2 METHODOLOGY

In recent years, constructive design research (CDR) has emerged as a prominent methodology within the fields of design and human-computer interaction. Characterised by its iterative and practice-based approach, CDR bridges the gap between theoretical inquiry and practical application through the creation and study of design artefacts. In the CDR, artefacts refer to the tangible and intangible objects created during the research process. These artefacts are central to CDR as they embody the design solutions and serve as the primary means of inquiry and knowledge generation. By creating and iteratively refining these artefacts, the researcher can investigate how different design elements influence user engagement.

Three main approaches to research through design are Lab, Field and Showroom. The essence of the 'Lab' approach is characterised by a theoretically inspired design process, and the designs can be seen as physical hypotheses. Systematic variations of the prototypes are tested in controlled lab experiments, using quantitative data and statistics to demonstrate causality. The aim is to come to generalisable design knowledge, frameworks and theory [11].

The essence of 'Field' is that design is investigated in its natural context of uncontrollable settings. It is based on design ethnography, driven by understanding, rather than causality, and a focus on how people create meaning with the new designs in their everyday environment. The aim is to generate situated knowledge and understanding [11].

In the 'Showroom' approach it is where research meets design and art. However, design can come closer to reality than art. Showroom is an umbrella term for critical and speculative design research, where the aim is to go beyond knowledge, and ask novel, uncomfortable, but relevant questions, rather than providing comforting answers. It is research and design for debate; where the task of design is to take drifts and detours from established practices [11].

In the model of constructive design research, hypothesizing is an ongoing activity that evolves in response to experimental findings and is continuously shaped by the overall goals and research questions. This approach emphasizes the iterative nature of research, where hypotheses are not fixed but adapt and develop through a process of experimentation and reflection [12].

In the framework of constructive design research, this thesis involves developing and testing the interaction design of a sidewalk robot. The research unfolds through iterative phases, integrating physical prototyping, user feedback, and real-life experimentation to refine the robot’s design. Throughout the research, hypothesising is an ongoing process dynamically shaped by experimental findings. Each phase of testing informs the next, creating a feedback loop that continuously refines both the hypotheses and the design elements. The experiment acts as the central "drive wheel," guiding the research and ensuring that the design remains responsive to real-world interactions and user feedback.

# 3 BACKGROUND STUDY

## 3.1 How Sidewalks are Used

Walking is the oldest form of urban transport, and until the advent of major transformations in transport technology in the nineteenth century, most cities were structured in ways that supported walkability [13]. Humans, the inhabitants of cities, primarily use sidewalks for walking but also engage in various other activities such as cycling, skating, playing, communicating, doing business, people-watching, and walking dogs. Beyond walking for access to goods and services, these other activities in urban spaces are collectively referred to as 'sojourning'. Walking and sojourning are at the heart of urban life and contribute to liveable, attractive, prosperous and sustainable cities [14].

While walking is basically a linear movement that brings the walker from place to place, it is also much more [15]. The nature of a walk varies depending on its purpose. Quick goal-oriented walk from A to B, the slow stroll to enjoy the city life or a sunset, children's zig-zagging, and senior citizens' determined walk to get fresh air and exercise or do an errand [15]. Walking in urban areas is also much more than just walking. There is direct contact between people and the surrounding community, fresh air, time outdoors, the free pleasures of life, experiences and information. And at its core walking is a special form of communication between people who share public space as a platform and framework [15].

### 3.1.1 Walking

Walkability is one of the factors that influence the health outcomes of city dwellers. The term walkability summarises features of the urban built environment that promote walking and other types of physical activity [16]. Walking is the most fundamental form of mobility. It is inexpensive, emission-free uses human power, is not fossil fuel, offers important health benefits, is equally accessible for all - except those with substantially impaired mobility - regardless of income, and for many citizens, is a source of great pleasure [14]. Walkability encourages active transport such as walking and biking but also recreational walking and biking [16]. There is a substantial difference between active transport and recreational walking and biking. In the first case, a person uses urban space to travel from one place to another. In the second case, they use the space for leisure activities or physical exercise. Both improve the general physical activity of the population [16]. The health impacts of active transport have been intensively studied and a systematic review provides strong evidence that active transport provides substantial net health benefits even if negative health impacts like accidents and exposure to air pollution are taken into account [16].

An important prerequisite for a comfortable and pleasurable walk is room to walk relatively freely and unhampered, without having to weave in and out and without being pushed and shoved by others [15]. Before the invention of cars, street space was not strictly divided between different road users, such as pedestrians, cyclists and horse carriages. If we look at photographs from 100 years ago, pedestrians are often shown moving freely and unimpeded in every direction [15]. This behaviour stems from the natural movement patterns inherent to humans. When pedestrians can see the object of a walk, they rechart a course along the shortest distance [15].

However, the shortest distance may not always be possible due to the presence of various obstacles on the sidewalks. Traffic signs, lampposts, parking meters and all types of technical control units are systematically placed on sidewalks in order "not to be in the way." [15] As modern technologies advance, new obstacles are introduced to the sidewalks, including rental micromobility vehicles and delivery robots.

### 3.1.2 Micromobility

With the growing population of cities, an increase in the number of pedestrians as well as micromobility vehicle users can be expected. "Micromobility" refers to personal vehicles that are significantly smaller and lighter than cars [17]. Micromobility vehicles come in a range of established (e.g. bicycles), less established and rapidly evolving form factors (e.g. standing or seated e-scooters, electric unicycles, powered skateboards, etc.) [17].

In this thesis, "micromobility vehicle" refers to the type A classified vehicles: powered or unpowered vehicles weighing less than 35 kg and with a maximum powered design speed of 25 km/h [17]. These vehicles include those that require human exertion to move, such as bicycles, pedal-assist e-bicycles, kick-scooters, and skateboards, as well as e-scooters, electric unicycles, powered skateboards, and more. Type A micromobility vehicles are typically observed being used on sidewalks.

With limited space and a growing number of sidewalk users, policymakers and city planners face the challenge of creating safe infrastructure and ensuring accessibility for micromobility users without endangering other sidewalk users, such as pedestrians and mobility aid users. Many companies have responded to the challenges of denser traffic conditions by offering micromobility services, such as e-scooter and e-bicycle rentals. However, this practice has proven controversial as the usage of such vehicles is often unregulated. In some cities where it's prohibited, users of electric-powered micromobility vehicles have illegally taken to the sidewalks, resulting in accidents [17] and blocking pedestrian pathways with parked devices, leading to disturbances [18]. Laws regarding micromobility vehicles vary between countries [19], with some places imposing restrictions on their usage. For example, Paris became the first city to ban rented electric scooters in 2023 [19].

### 3.1.3 Micromobility Safety

Most reported micromobility crashes result in only minor injuries [17]. According to available data and studies, fatality rates are very low for all injury-inducing crashes (<1%), with no clear difference between e-scooters, e-bikes and conventional bikes [17].

The severity of injuries sustained in accidents is influenced by various factors, including crash mechanisms and the type of vehicle involved. E-scooter riders, which typically adopt a free-standing and upright posture, have a high and forward centre of gravity. In cases of loss of control, riders may attempt to hop off the e-scooter, leading to lower extremity and foot injuries. Alternatively, riders may be catapulted forward and over the handlebar, resulting in face and head injuries. Riders may make contact with the ground head first [17]. Cyclists, on the other hand, are more likely to sustain injuries to their upper extremities, thorax, or spine [17].

The majority of micromobility crashes involve only the rider and no other road users. These single-road user collisions often occur due to falls resulting from loss of vehicle control or collisions with stationary objects. Such incidents account for up to 93% of all reported e-scooter-related casualties, a proportion comparable to that of cyclists [17].

Evidence indicates that e-bikes tend to have a higher conflict rate compared to conventional bikes, regardless of fault. Conflicts are most likely to occur between e-bikes and pedestrians, while the conflict rate is lowest between two conventional bicycles. Overall, however, evidence indicates that the dangerous driving behaviour of car drivers causes the most observed conflicts [17].

### 3.1.4 Pedestrian Safety and Micromobility

Falling is the most common accident happening with pedestrians on sidewalks. Pedestrian falls account for up to 75% of pedestrian injuries [14]. Another risk with using sidewalks involves micromobility. Pedestrians are exposed to crash risk in contexts where micromobility riders, legally or illegally, use the sidewalk in the presence of pedestrians. This is especially the case in the absence of bicycle infrastructure. In accidents involving pedestrians, they are injured through collisions or tripping over parked e-scooters or fallen bicycles [17]. Although there are no statistics suggesting that delivery robots are a considerable risk to pedestrians, it can be assumed that also robots standing still on sidewalks can be an additional obstacle for pedestrians.

Keeping sidewalks free from unnecessary obstacles is not only a question of walkability and comfort. The barrier-free design promotes mobility for all pedestrians, regardless of their level of functional ability. It is essential to cater for the mobility impaired, but a barrier-free road and path network can benefit all pedestrians [14]. Obstacles on footpaths are considerable barriers, for the visually-impaired as well as for people with impaired mobility and for those who use wheelchairs [14].

## 3.2 Moto-normativity

As space is limited, it is also valuable. With the growing population, city dwellers face the hindrance of overcrowded sidewalks, especially in city centres and around public transportation stations. This situation creates a conflict of interest among road users, such as car drivers, pedestrians, and micromobility riders. Over the past century, car-centric development has led to moto-normativity. Moto-normativity, an often unnoticed bias favouring motorized transportation, influences both individual choices and policy-making. This bias arises from cultural assumptions that prioritize private car ownership, sometimes leading to policy decisions that overlook alternative transportation options or fail to address the negative impacts of car-centric infrastructure. It essentially creates a default acceptance of the risks and drawbacks associated with motor vehicles [6].

British-Venezuelan scholar Carlota Perez has specialized in researching technology and socio-economic development. According to her, during the past 240 years, the world has undergone five technological revolutions. Each revolution had its technological inventions that led to paradigm changes in lifestyles [7]. The fourth revolution was the Age of Oil, the Automobile and Mass Production, which made suburbanization possible [7]. The blooming automotive industry and networks of roads enabled families to commute between cities and suburban areas. The widespread suburban living further expanded the market for automobiles [7].

Although at the beginning of the 20th century, streets were not strictly divided between different road users, this changed as the number of cars rapidly increased. This led to a growing number of traffic accidents and the need to optimize traffic flows.[20]. In step with the car invasion, pedestrians were first pushed up along building facades and then increasingly squeezed together on shrinking sidewalks [15]. Streets became socially reconstructed as places where cars undoubtedly belonged [20].

This shift in paradigm paved the way for the automotive industry to promote the idea that cities should be redesigned to prioritize and facilitate the traffic flows [20]. When seeking solutions to traffic congestion problems, traffic engineers assumed that cities contain a relatively fixed quantity of transportation needs and expanding the roads would resolve it. However, it turned out that increasing roadway capacities wouldn't resolve traffic congestion issues, as it motivates more people to drive cars. This phenomenon is widely known as induced demand [21].

While engineers go to great lengths to evaluate automobile flow, they pay far less attention to the throughput and safety of pedestrians and cyclists, as well as to public transit [20]. For the past 100 years, urban infrastructure and road-design standards have focused primarily on meeting the needs of motorized vehicles, with the needs of pedestrians and cyclists being secondary considerations [5]. Undoubtedly, it affects the walkability of the cities. Studies of urban streets in London, New York and Sydney illustrate the problems of narrow sidewalks for large crowds of pedestrians on streets where most of the area is designed for car traffic, despite the fact that the number of drivers is far lower than the number of pedestrians crowded together on the sidewalk [15].

### 2.2.1 Impacts of Moto-Normativity on the Public Health

The changes in urban life over the past century have also impacted public health. The World Health Organization recommends at least 300 minutes (5 hours) of physical activity per week, which can be achieved through various means such as walking, cycling, sports, or active recreation [5]. Globally, physical inactivity ranks as the fourth leading cause of mortality, following high blood pressure, tobacco use, and high blood glucose, contributing to 6 per cent of worldwide deaths [5]. Physical activity also benefits mental health, including prevention of cognitive decline and symptoms of depression and anxiety, and improves children's educational achievements [16]. Sedentary work has largely replaced manual labour from the past, while cars have increasingly become the dominant mode of transport [15].

The benefits of active transport have a wider impact than personal advantage.x Leading a healthy life due to improved health is crucial not only for individuals but also for society, as good health and life satisfaction enhance overall productivity and result in economy-wide cost savings [6]. Car-centric urban planning directly impacts walkability and active transport. Assumptions rooted in moto-normativity may hinder efforts to promote walking, cycling, and diverse uses of urban public space [6].

## 3.3 Paradigm Shift in Lifestyles

After the fourth technological revolution came the fifth: the Age of Information and Telecommunications [7]. It started in 1971, when Intel released the world's first microprocessor [22], followed by the invention of the internet in 1983. The ICT revolution has enabled us to communicate directly with anyone connected to the internet, including various service providers, e-commerce companies, and restaurants.

### 2.3.1 E-commerce and the Last Mile

E-commerce provides us with a greater range of goods, better prices, 24/7 availability, and deliveries to our door. It includes consumer goods from electronics to groceries, as well as prepared meals and drinks. Over the past two decades, e-commerce has significantly contributed to the increase in urban freight flow, both in freight volume and freight traffic [23].

The final leg of the business-to-customer supply chain is when the shipment is delivered to the recipient, either at their home or at a collection point [23]. This is commonly called the "last mile." Last-mile logistics is the least efficient and most complex part of the supply chain. It contributes to greenhouse gas emissions, congestion, air and noise pollution, traffic accidents, and damage to infrastructure such as road networks [23]. Figuratively speaking, a car weighing several tonnes and using fossil fuels takes up valuable space and wears out the asphalt just to deliver one pizza.

Many companies have already reacted to the last mile problem by providing options such as mobile platforms where freelance couriers can deliver meals and goods. Some of these couriers use micromobility vehicles, riding them on roads, bike lanes, or sidewalks, depending on the available infrastructure. Another possible solution introduced to cities is autonomous robot deliveries. These autonomous robots operate in Europe, North America, and Asia.

Although using sidewalks for delivering goods potentially reduces the pressure of e-commerce on motor vehicle traffic, it also raises ethical questions. Pedestrians have already been forced to adjust to the increasingly crowded conditions of the sidewalks. In cities without a sufficient network of light traffic roads, micromobility for transporting people is already taking up space on sidewalks and raising safety concerns. Now, as roads become congested with motor vehicles, the transportation of goods is also moving to the sidewalks. This shift places a significant social responsibility on the companies providing such services, as well as on the governments that need to manage who and how the sidewalks can be used.

## 3.4. Sidewalk Robotics

### 3.4.1 Introduction to the Sidewalk Robotics

The ICT revolution has given us affordable and compact electronics that can be used to develop various devices, from mobile phones to delivery robots. For new technologies to emerge, several conditions must be met. Firstly, there must be a need for such technology, which comes from changes in general lifestyle. Additionally, various resources are needed to develop these technologies. For delivery robots to come into existence, technological prerequisites include affordable and compact electronics, such as microchips, cameras, radars, and ultrasound sensors. Services such as GPS, fast internet, and servers are also necessary. However, hardware and services alone are not enough. Without the knowledge to develop advanced software, computer vision, neural networks, and automation, these technologies would not be achievable.

In March 2018, a self-driving sidewalk delivery robot from Starship Technologies completed the world's first commercial L4 autonomous driving. By April 2023, Starship robots had driven 10,000,000 kilometres; by May 2023, Starship robots had completed 5,000,000 autonomous deliveries [1]. L4 (level 4) autonomy refers to High Driving Automation, where automated driving features can drive the vehicle under limited conditions. Level 4 automation does not require a human to operate the vehicle, and when the conditions are not met, the vehicle stops [24]. Following Starship Technologies, many other sidewalk delivery robot companies launched their operations worldwide. To name a few: Kiwibot (US) [25], Amazon Scout (US, discontinued in January 2023) [26], and Yandex (Russia) [27].

As the field of robotics is developing rapidly, it can be predicted that delivery robots are not the only service robots that will operate on our streets in the future. There are already, for example, police patrol robots that can broadcast audio and visual messages and deploy interim intervention measures such as blinkers, sirens, and speakers to enforce a cordon or warn bystanders prior to the arrival of police officers. Also, members of the public can activate a button located on the robot’s front to communicate directly with the police [28].

As the field of robotics develops further, city dwellers can expect an increase in the number of robots on sidewalks worldwide. These robots' functions will not be limited to delivering various items; instead, they will be used to perform numerous tasks.

Due to this expansion of roles, I will refer to autonomous vehicles running errands on sidewalks as "Autonomous Sidewalk Robots" (ASRs) in this thesis.

## 3.5 Published Research

As the phenomenon of ASRs is relatively new, academic research in the field has yet to reach saturation, and more questions are raised than answered. However, there has been an increase in research on the topic. Some circumstances must be considered when studying related research on the subject. Firstly, most of the research is relatively new, providing the opportunity to work with the latest data. Secondly, technology advances so rapidly that research may become outdated quickly. Research on autonomous robots on sidewalks involves various approaches, including studying intentional interaction between the robots and humans, conflict situations, and focusing on acceptance or more subtle reactions while sharing the sidewalks. This research is typically conducted in the robots' natural habitat.

### 3.5.1 Social Interaction

When robots are first introduced to a city or area, residents begin to make sense of them, which is a form of creating public knowledge. People engage in sensemaking when the anticipated flow of their environment is interrupted by something surprising [29]. In a research project in Pittsburgh where Kiwibot robots were tested in a pilot, members of the public offered explanations, such as robots delivering pizza or mail from the post office [29]. They also shared their personal opinions about the robots, such as “That seems like an expensive way to deliver pizza,” “So dumb” and “It looks so fucking stupid [29].” Another set of questions people have are technical ones. “Is someone controlling that,” “How many of these are there [29]?” But also information was shared: “I think they all have cameras on them. They’re watching us, and they’ll know if we touch it [29].”

In a study performed in Tallinn, the authors found from online discussions that commentators were unsure whether helping robots is appropriate or desirable. Some commentators mentioned how failures might be helpful for developers as this is how robots learn and improve [30]. One person was inclined to help a robot but was unsure if they were allowed to do so and how [30].

Spontaneous interaction between humans and sidewalk robots can be either intentional or circumstantial. One form of intentional interaction is motivated by curiosity. Across observations in Pittsburgh research, pedestrians were open to interacting with the device when they believed it could communicate back [29]. Pausing when seeing a robot is a very common reaction to a robot [29], [30], as is taking photos and videos [29], [30]. In one instance, Tallinn researchers observed a person with a professional photo camera who slightly pushed a robot off its path to take pictures of it [30].

Curiosity is especially evident in the case of children. The authors of the Tallinn research found that both dogs and children were particularly curious about the robots. Children followed the robot along its path and engaged in conversations about it with accompanying adults [30]. Similarly, in Pittsburgh, it was observed that many children would touch, stare, and block the device in an attempt to understand this interruption in their environment [29]. Additionally, researchers in the UK observed that young children playfully obstructed the path of the robot while observing the strange object [31].

The spontaneous interaction with sidewalk robots can vary between playful and malicious. In UK research, observations indicated that members of the street sometimes engaged playfully with the robots, such as waving and saying “oi” as a robot passed [31]. Similarly, in Pittsburgh, a man was observed nodding with a smile at the robot [29]. However, there were also instances of malicious interaction. In the UK, a person grabbed a robot’s antenna and pulled it [31].

Another form of spontaneous interaction is assisting a robot. Observations in both the UK and Tallinn revealed instances where pedestrians pressed a traffic light button for a robot attempting to cross a street [30], [31]. In Tallinn, heavy snowfall often led to robots getting stuck, prompting people to lend a hand. Passers-by cleared snow in front of the robot or gave it a gentle push to guide it along a clear path [30]. Additionally, individuals were observed removing obstacles from the robot's path when navigation was obstructed [30]. Similarly, in Pittsburgh, a woman assisted a robot that had fallen into a road verge. Her body language and facial expression suggested a sense of satisfaction in helping the device [29]. The question of the ethical aspects of helping the robots was raised by the authors of the Tallinn study. They argue that these concerns are especially pertinent in the case of commercially deployed technologies, where instances of passer-by help, no matter how enjoyable, will still reflect an aspect of hidden labour [30]. The authors of the Pittsburgh study emphasized that there needed to be more clarity on how to interact with it, especially when there was a need for hands-on interaction, such as helping the robot to unstuck [29].

A unique scenario involves humans interacting with sidewalk robots while carrying out their work duties. In Pittsburgh, a construction worker lifted a vacuum tube for a robot to pass underneath [29]. Similarly, during the UK study, a window cleaner paused their work upon noticing an approaching robot and made way for it to pass. Instead of speeding up and passing the window cleaner fast, the robot instead slowed down. The cleaner then said, "Come on, then", and while giving the robot a little kick ", Hurry up [31]." Another observation from the same research involved a worker delivering goods to a restaurant; they pulled their trolley away from the robot's path to make way for it [31].

The UK study revealed that pedestrians often adjusted their behaviour to accommodate robots. This included actions such as moving to the outer edge by the pavement kerb and squeezing past a lamppost or twisting their body sideways and lifting their shopping bag to maintain distance from the robot and post [31]. However, instances of more problematic robot behaviour were also noted. For example, when a robot abruptly braked, a pedestrian walking behind it almost bumped into it and extended their arm to maintain balance. There were many such encounters, and the authors of the research concluded: "This illegibility of robot mobility demonstrates potential dangers to members of the street, with the robot itself turning into an obstacle, ironically—it turns out—as part of its own obstacle avoidance routines [31]." The analysis of online data in the Tallinn study revealed a generally favourable perception of Starship robots and their encounters with them. [30]. People commonly described the robots as "cute" and "adorable," often using diminutive nouns such as "little guy" and "buddy" to refer to them [30]. The authors speculate that this perception of the robots as harmless likely contributed to their overall acceptability among the public [30].

### 3.5.2 Incidents Involving ASRs

A study from Northern Arizona University (NAU), USA, aimed to generate new evidence regarding the traffic safety experienced by active travellers who share pathways with autonomous robots [32]. To gather the data, the authors filmed the most crowded locations on campus during rush hour, identified all the interactions between humans and robots, and used a statistical model to evaluate the severity of the interactions. In conclusion, the authors stated that the severity of the incidents increased when a robot crossed the intended trajectory of a human pathway user, often leading pedestrians or bicyclists to alter their path to avoid a collision [32].

The results of the NAU research show that conflicts happen despite the environmental potential for smooth interaction. During the observations, they identified 201 incidents between human pathway users and sidewalk robots. Of these, 106 were classified as moderate or dangerous. Twelve of those interactions resulted in a crash or a human's body being straight over the identified crash point. In the case of pedestrians, all dangerous conflicts and 87% of moderate conflicts resulted in human swerving. The same pattern is evident in bicyclist-ASR interaction cases [32]. In most interactions (57%), the robot was the first pathway user to reach the conflict zone, thus initiating the conflict with the human pathway user. Nearly half (47%) were crossing conflicts where the paths of humans and robots intersected [32]. From those results, it could be discussed whether the robots lack the ability to resolve conflicting situations with human sidewalk users.

## 3.6 Legislation and Social Responsibility

### 3.6.1 Legislation

The first traffic law was the Locomotives on Highways Act of 1865 in Britain, which reduced permissible speeds of steam coaches on public roads to 2 miles (3 km) per hour within cities and 4 miles (6 km) per hour in rural areas, a warning red flag to be carried in front of each locomotive [33]. Since then, traffic management has evolved in step with the automotive industry. In addition to regulating the movement of drivers, cyclists, and pedestrians, many countries have already started regulating new micromobility devices such as e-scooters. Furthermore, several countries have introduced sidewalk robots into their road traffic legislation.

Estonia was the first country to introduce the term “self-driving delivery robot” (“robotliikur” in Estonian) into the Road Traffic Act in 2017 [34]. In a few countries where delivery robots operate, there are no specific laws to regulate the usage of autonomous robots on public sidewalks. However, companies are negotiating exemptions to permit small-scale pilot projects [35].

In legislation, the technical parameters of ASRs are typically described, including dimensions, mass, speed, safety reflectors, and other requirements [35], [36], [37]. In Finland, ASRs fall under the category of “light automatic goods carriers,” which are required to give pedestrians clear passage, take special caution when driving on pavements, and adjust their speed to avoid harming or endangering pedestrians [38]. Estonian legislation also stipulates that the user of a delivery robot must be careful, cautious, and alert to prevent endangering other road users and causing damage [37]. However, the legislation is not very specific on how ASRs need to act on sidewalks or how to ensure the safety of human sidewalk users. It passes the social responsibility of guaranteeing safety to the companies and opens up vast opportunities for interaction designers.

### 3.6.2 The Social Responsibility

As companies deploy fleets of ASRs onto sidewalks, they also bear the responsibility of designing features that prevent conflict situations between humans and robots. As autonomous robots run their errands on overcrowded sidewalks, safety must be considered. When it comes to micromobility, the riders are usually a threat to themselves due to high speeds that lead to the inability to react to potential obstacles. Sometimes, though, they are also a threat to others, as described previously.

While ASRs' low speed makes them relatively safe to share sidewalks with, it's not without its challenges. With ASRs roaming on the sidewalks, micromobility vehicle riders have one more obstacle on their way and also pedestrians have to make their way around the robots. It's particularly concerning for more vulnerable individuals, such as blind and low-vision pedestrians, who have expressed concerns about rental e-scooters on sidewalks worldwide [39], [40]. With ASRs introduced into the mix, it adds yet another obstacle.

Companies need to ensure the safety of people with visual impairments, which involves addressing several aspects. Firstly, while walking on the sidewalk, visually impaired people need to know about the presence of the ASR. However, there is currently no established standard for resolving this issue through interaction design. Another concern is that guide dogs may be afraid of the ASRs. This has led to cooperation between Starship Technologies and UK-based Guide Dogs training centre, where the company donated a robot shell to the training centre where it's used to socialize the guide dogs with the robots [41].

For mobility aid users, narrow spots might become a barrier when they cannot pass the robot along the way [42]. Furthermore, for the elderly, who are not as agile anymore, rapidly stopping and swerving robots might be threatening. The fear of falling may lead them to avoid activities such as walking, shopping, or taking part in social activities [43]. Losing balance and falling is especially dangerous for them, as their bones are fragile. A broken bone can also be the start of more serious health problems for older people and can lead to long-term disability [43].

### 3.6.3 Stakeholders

The integration of ASRs into urban environments requires an understanding of the diverse interests at play. Stakeholders, including communities, customers, companies, partners, and governments, each contribute to the problem set. Communities, such as local residents, urban activists, and NGOs advocating for people with disabilities, promote walkability and accessibility. Their interest is in having a safe environment free from obstacles. Communities' concerns about accessibility and safety issues related to ASRs need to be addressed to gain and maintain public acceptance.

While customers prioritize efficient delivery services, their interest is in smooth operation on sidewalks, which can be improved by enhancing ASRs' capabilities to navigate around humans regardless of their moving methods. Companies and partners perceive ASRs as avenues for business growth and market expansion. Acceptability among communities is crucial for such operations to happen. Efficient operation on sidewalks directly influences business outcomes. Concurrently, governments uphold regulatory frameworks to ensure safety and orderliness while fostering innovation and maintaining social responsibility.

## 3.7 Interaction Shortcomings

From research, it's evident that communication between ASRs and humans has room for improvement. There is a lack of understanding regarding what ASRs are doing on the sidewalks, both in broader and more specific contexts. In broader contexts, people don't know the purpose of the robots, whether they should interact with them, and if so, how. This often leads people, upon seeing an ASR roaming down the street, to create a narrative to make sense of the phenomenon.

In a narrower context, there is direct interaction between humans and ASRs when they share the sidewalks, requiring both parties to predict each other's next steps. Humans rely on their life experiences to interpret the information they gather regarding the behaviour of other individuals. However, this dynamic does not work as effectively between ASRs and humans.

Animals that move in flocks follow mutual alignment rules, with the most important being to move in the same direction as their closest neighbors [10]. This automatic alignment behavior is also observed in humans [10]. In order to behave adaptively, individuals use social information, including movement variables such as velocity, acceleration, and alignment, to respond to the behavior of their neighbors [9].

### 3.7.1 Differences in Moving Patterns

To explore the interaction between different groups of sidewalk users, it's necessary to understand how they move. Humans rely on the movement of others as important social information to plan their own movement.

**Motor vehicle traffic**

Motor vehicle traffic is fundamentally linear. Cars and other motor vehicles typically travel within their designated lanes, and all intersections with other vehicles are strictly governed by traffic laws or management tools such as traffic signs, lights, and road markings. These regulations aim to minimize the occurrence of dangerous situations and accidents. Meeting points between motor vehicles and other groups of road users are also usually tightly regulated. For instance, crosswalks and bicycle crossings are implemented to reduce the risk of vulnerable groups being struck by motor vehicles.

### Walking as Active Transportation

When considering walking as active transportation, most cities provide sidewalks, footpaths, pedestrian areas, or road shoulders dedicated to this purpose. As mentioned earlier, individuals typically walk directly towards the object of their walk. On sidewalks, this movement is confined within the boundaries of the sidewalk, defined by the curb, green areas, or buildings. While walking, individuals are usually agile and may use non-designated spaces, such as stepping onto car roads or traversing grass if necessary. Although in countries with right-side traffic, it's common to use the right side of the sidewalk, and in countries with left-side traffic, it's common to use the left side. This is not a strict rule, and pedestrians may choose the side that suits their needs. For example, they might opt for the left side if they plan to turn left soon.

### Sojourning

lacks consistent patterns. People might stand, move crisscross, and block entire sidewalks while interacting with other people. While staying on sidewalks, adults might be accompanied by toddlers whose trajectories are erratic. Some people have dogs on leash.

### Micromobility

Micromobility vehicle riders, on the other hand, move 4-5 times faster than a purposefully moving pedestrian. Although micromobility vehicles typically travel in as straight a line as possible, the difference in speed poses pedestrians as obstacles to navigate around. Additionally, ASRs present obstacles for micromobility users. Since movement on sidewalks is irregular rather than linear, a pedestrian or ASR suddenly deviating from their initial trajectory might catch riders by surprise. In such cases, it depends on the foresight and skill of the rider to avoid accidents. Stationary objects also force micromobility users to swerve.

### Sidewalk robots

In countries with right-side traffic, ASRs primarily move on the right side of the sidewalks, while in left-side traffic countries, they drive on the left side. Based on the author's autoethnographical observations, their moving pattern ASRs resemble cars the most. They move straight unless there is an obstacle in the way, in which case they move tightly around the obstacle. On street corners and places where they need to turn away from their initial trajectory, ASRs often perform 90-degree turns, just like cars at intersections. However, this movement pattern contrasts with pedestrian behaviour of walking as straight as possible towards the object of the walk. Despite their relatively slow speed, sudden stops turns, or starts by ASRs can be unexpected for human sidewalk users.

Figure 1 illustrates the interaction between a pedestrian and a micromobility rider, as well as between an ASR and a micromobility rider. The first image illustrates how the pedestrian would bypass an obstacle and turn around the corner. The second image shows the path of the micromobility rider in this situation. The third image depicts the trajectory of a robot when encountering the obstacle and later turning left. The fourth image combines the trajectory of the robot with that of the micromobility rider and highlights potential conflict zones.

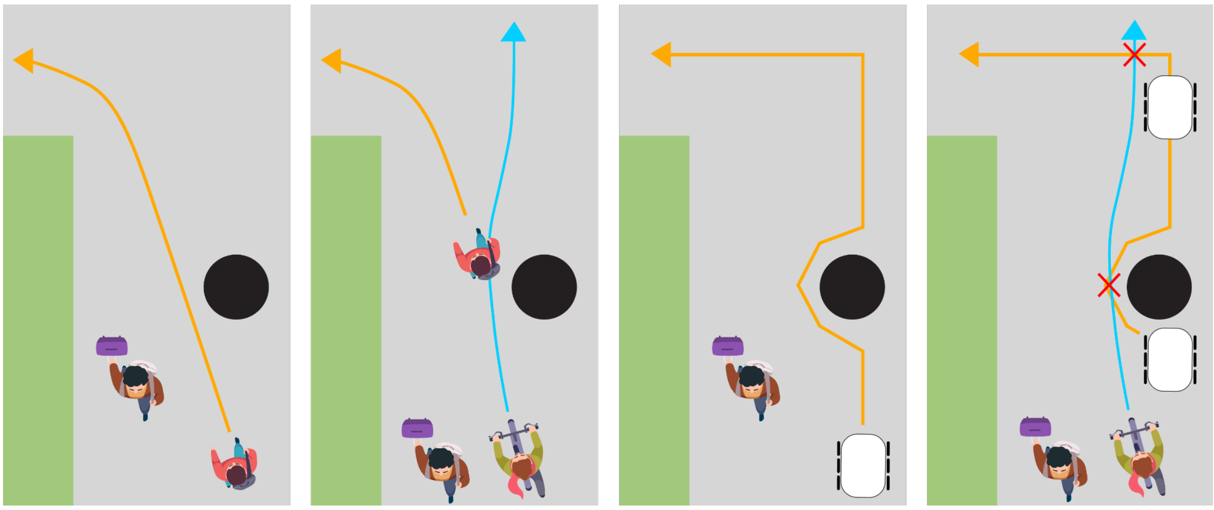

Figure 1 Different moving patterns

### 3.7.2 Human Speed vs ASR Speed

The human species is adapted to walking at 5 km/h [15]. allowing us to maintain sensory contact with our surroundings, gather information, evaluate situations, and react effectively. Additionally, running at around 10-12 km/h and cycling at 15-20 km/h provide decent contact with the surroundings, although sometimes we need to slow down to assess situations better [15]. Starship delivery robots have a limited maximum speed of 6 km/h in most service areas, whereas Kiwibot's average speed is 3 km/h [25]. This speed allows humans to perceive their presence and observe their actions. This speed allows humans to perceive their presence and observe their actions, providing a good foundation for pedestrian-ASR interaction but posing some more challenges for micromobility-ASR interaction.

### 3.7.3 ASRs as a Separate Group of Sidewalk Users

As it can be expected that ASRs with different work tasks will become more common, they could be classified as a separate group of sidewalk users and ideally have consistent behavioural patterns. To achieve this, there need to be standards or well-established examples of ASR interaction design. This thesis aims to constructively research what kind of interaction elements could benefit the interaction between humans and ASRs.

To ensure smooth interaction between ASRs and humans, the machines need to be predictable, allowing humans to learn their behaviour. However, the machines also need to be developed to adapt better to the complex and continuously changing environment of sidewalks. Some robot behaviours that deviate from human behaviour may need to be aligned better with established social norms.

## 3.8 Cultural Influences

As described previously, when Pittsburgh citizens first saw the ASRs, they tried to make sense of the oddity they had just experienced. This led to them coming up with their own explanations of what those robots are and why they are there. Humans often use analogical reasoning to explain the unknown. Analogical reasoning involves drawing comparisons between familiar situations or concepts and unfamiliar ones to make sense of new information or solve problems [44].

### 3.8.1 The Cuteness Factor

The concept of baby schema suggests that humans are instinctively drawn to features commonly associated with infants, such as large eyes, rounded faces, and small noses, due to their association with vulnerability and helplessness. As a result, objects or creatures possessing these features are perceived as less threatening and evoke feelings of affection and protection [45]. Although ASRs commonly do not have facial features, their rounded bodies, intentionally designed to increase acceptance, are still perceived as cute, which surges the desire to communicate with them. From the Tallinn research, it was found that people like the cuteness of the robots. It could be argued that people's willingness to interact and the cuteness factor may add an exciting new feature to the cityscape.

### 3.8.2 Personality and Values

As companies deploy fleets of ASRs onto sidewalks, they bear the responsibility of designing the robots' etiquette, safety, and interaction features to prevent any conflicts. While humans are adaptable, this adaptability cannot be taken for granted. In popular culture and science fiction, ethical dilemmas of robotics are common topics. It can be argued that since ASRs are intentionally designed to consider the cuteness factor, humans likely expect them to act harmlessly and adhere to cultural norms derived from these cultural phenomena. One of such commonly acknowledged norms is The Three Laws of Robotics by Isaac Asimov, an American science fiction writer. The First Law reads: “A robot may not injure a human being or, through inaction, allow a human being to come to harm [46].”

To align with this principle, robots should prioritize the well-being of human sidewalk users. Figuratively speaking, the cornerstone of enhancing ASRs' interaction capabilities lies in the development of the robot's personality and values. Consistency in behaviour instils a sense of security in humans, reassuring them that the robot will respond predictably in various situations. Similarly, adherence to acceptable values provides humans with the confidence that the robot will not engage in behaviours that could pose harm.

In the development process, robot developers can utilize these personal values as guiding principles for shaping the behaviour and characteristics of ASRs. By embedding coherent personality traits and acceptable values into the design and programming of ASRs, developers ensure that the robots align with human expectations and ethical standards. This approach not only enhances user trust and confidence but also promotes the responsible and ethical deployment of autonomous technology in human-centric environments.

When considering the personal values that sidewalk robots could possess, safety, adaptability, and courtesy align with The First Law. Safety, as the primary value, prioritizes navigating sidewalks in a manner that minimizes risks to all parties involved. Adaptability involves situational awareness and responding to changing conditions without impeding the movement of any human sidewalk user. Courtesy embodies giving right-of-way to pedestrians, yielding when necessary, and avoiding behaviours that might inconvenience or startle humans. Open communication is a prerequisite for these values. In the case of robots, the foundation of open communication lies in indicating their intentions.

## 3.9 How to Have an Interaction

Communication cannot occur without shared understanding. When people observe one another, behavioural alignment can be detected at many levels, from the physical to the mental [10]. When considering human-ASR interaction on sidewalks, humans may anticipate ASRs aligning with their behaviour, including using similar moving patterns, as a fundamental aspect of communication. This expectation underscores the importance of designing ASRs to navigate sidewalks in a way that aligns with human norms and expectations.

### 3.9.1 Senses in Common Between Humans and ASRs

Hardware provides robots with the senses they use to interact, allowing them to physically detect humans using stereo cameras, TOF (time-of-flight) cameras, ultrasound sensors, and radars. It also enables robots to react to humans by slowing down, stopping, reversing, turning, blinking lights, and emitting sounds. While humans primarily rely on sight and hearing to interact with ASRs, they also use touch, such as patting them or pushing them to get unstuck. However, sometimes, touch may be used maliciously.

The software enables robots to assess the physical characteristics of a situation and react based on their programming. When a robot detects a human, it calculates the potential meeting point based on their speed and direction. However, robots cannot assess human intentions or predict their next actions. Additionally, robots may struggle to differentiate between friendly and unfriendly touch interactions from humans. For instance, when a human pushes a robot, it activates its brakes to prevent unwanted movement. Yet, the human's intention might be to assist the robot in navigating through thick snow, making braking an inappropriate response. In contrast, humans rely on their life experiences and cognitive skills to evaluate situations and respond accordingly.

## 3.10 Research Question and Hypotheses

The background study highlights the complexity of the issue by showing how various factors, such as human behaviour in their natural environment, the rapid advancement of technology, the influence of motor-centric norms, and cultural aspects, are interconnected. While robots are often perceived as cute and likeable, research by various authors indicates that their behaviour can be unpredictable and divergent from human norms. To protect our cityscapes and ensure safe sidewalks for everyone, regardless of their abilities, these shortcomings in robot behaviour need to be addressed, leading to the research question: "How to improve autonomous sidewalk robot’s predictability among sidewalk users?”

The following hypotheses have been formulated to address the research question, "How to improve autonomous sidewalk robot’s predictability among sidewalk users?" and, more specifically, "What kind of interaction elements would benefit ASR's predictability?" These hypotheses are based on the assumption that specific design elements can significantly enhance the predictability of the robot’s behaviour toward pedestrians.

**Hypothesis 1: Visual Signals**

- Statement: Consistent visual signals on the sidewalk robot, such as LED indicators, enhance pedestrians' ability to predict the robot’s movements.

**Hypothesis 2: Displaying Intended Moving Directions**

- Statement: Displaying the robot’s intended moving directions increases sidewalk users' ability to predict its future movements.

**Hypothesis 3: Auditory Feedback**

- Statement: Auditory signals, such as beeps or voice prompts, enhance the predictability of the robot's actions for pedestrians by complementing visual signals.

**Hypothesis 4: Body Language Signals**

- Statement: The robot moving its wheels up and down or side to side before starting to drive helps pedestrians anticipate its movements.

# 4 CONSTRUCTIVE DESIGN RESEARCH

## 4.1 Introduction

As the phenomenon of ASRs is novel, the opportunity to design etiquette, safety, and interaction features is both exciting and challenging. Firstly, the domain is still in its early stages of development, which provides companies with a boundless playground. Principally, legislation about ASR operations is not very specific regarding how exactly robots should navigate nearby humans to avoid disturbances or conflict situations. Additionally, there is no established ASR etiquette or socially accepted ways autonomous sidewalk robots should communicate with humans.

The field of human-ASR interaction has yet to be thoroughly researched, and as a result, no refined interaction design samples have been deployed in commercial setups. Opportunities for improving human-ASR interaction are currently boundless. With the growing human population, enhancing and preserving urban spaces is crucial for providing a pleasant habitat for the human species. In an ideal scenario, sharing sidewalks with autonomous robots is not a nuisance for humans; ASRs are accepted and well-behaved features of urban areas; interactions are clear and smooth; and ideally, ASRs add value to city dwellers in general, not only to the users of the robots.

During constructive design research, this thesis explores opportunities to improve sidewalk robots' predictability through improvements in interaction design. The focal point of the research is chosen to be manoeuvering, as moving and changes in speed and direction pose the greatest risks of accidents.

### 4.1.1 Starship Robots

As the author of the thesis has access to the Starship delivery robots (Figure 2), they are utilized as research material. The Starship delivery robot is a six-wheeled, knee-high autonomous vehicle equipped with various sensors, including cameras, time-of-flight cameras, radars, ultrasound sensors, and GPS. Resembling a small cooler, the robot features rounded corners and a slightly domed lid. The middle and rear wheels are attached to bogies that enable raising the wheels for climbing curbs. Additionally, the robot is equipped with an orange blinking flag, white front lights, and red rear lights. Its lid can be opened to access the cargo basket.

Interaction elements currently used on Starship robots include white dimmable headlights. Red rear turn signals are activated a few moments before a manoeuvre takes place. These lights can change colours depending on the situation; for example, they turn white and blink while reversing. Between the turn signals is the "lid light," which indicates to customers where to open the lid. The flag light is used to catch the attention of road users. Given the small size of the robot, maintaining good visibility is important.

For auditory interactions, the robots use beeping sounds combined with white blinking lights to indicate their intention to leave the wireless charger. Sirens can be used if malicious people try to harm the robot. Pre-recorded audio clips and songs are played during interactions with customers and to thank members of the public for helping the robot.

Figure 2 Starship delivery robot (source: Starship Technologies)

## 4.2 Interaction Means

First and foremost, when planning improvements in interaction, the environment needs to be taken into account. As described previously, the environment is irregular and constantly changing (Figure 3). Other sidewalk users approach the robot from various directions and at different speeds. Fast-moving sidewalk users, such as micromobility riders, need to know much earlier what the robot's next manoeuvres are, whilst someone walking next to the robot needs to be able to understand the robot’s intention from very close proximity.

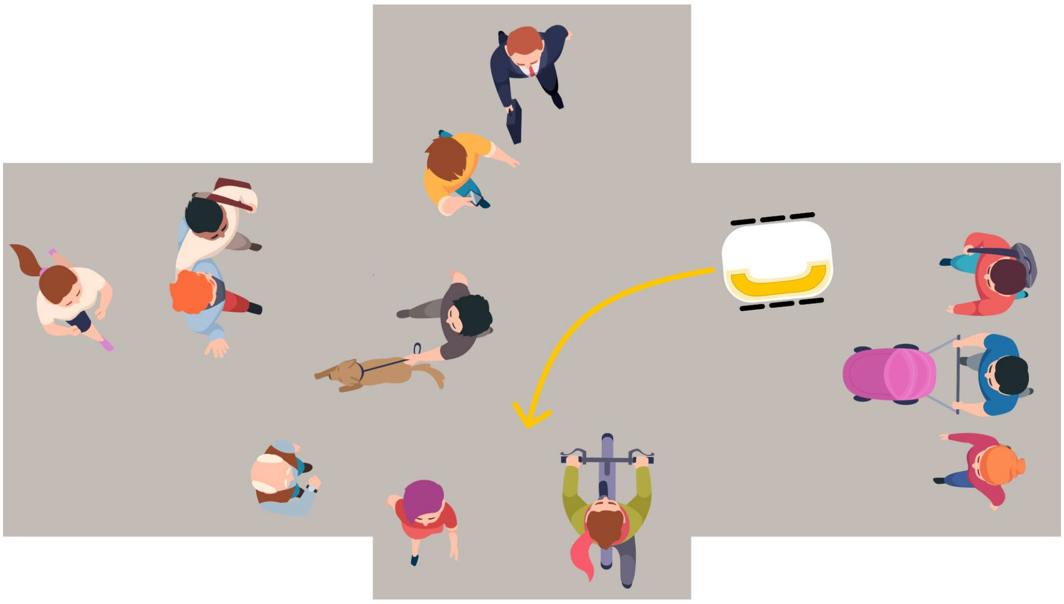

Figure 3 Irregular and constantly changing environment of sidewalks (source: author)

The constantly changing environment led to the idea of adding indicators on the robot's lid (Figure 4). As the robot is low, its lid is visible from various distances, and it’s also observable 360 degrees. To attract attention, sounds and bogie movements could be used. Bogie is a low framework on wheels [47]. The robot has one pair of regular wheels in front and one pair of bogies with two wheels each. The robot is capable of moving the bogies, a feature primarily used in situations such as climbing curbs and getting unstuck. This feature could also be used for interaction design.

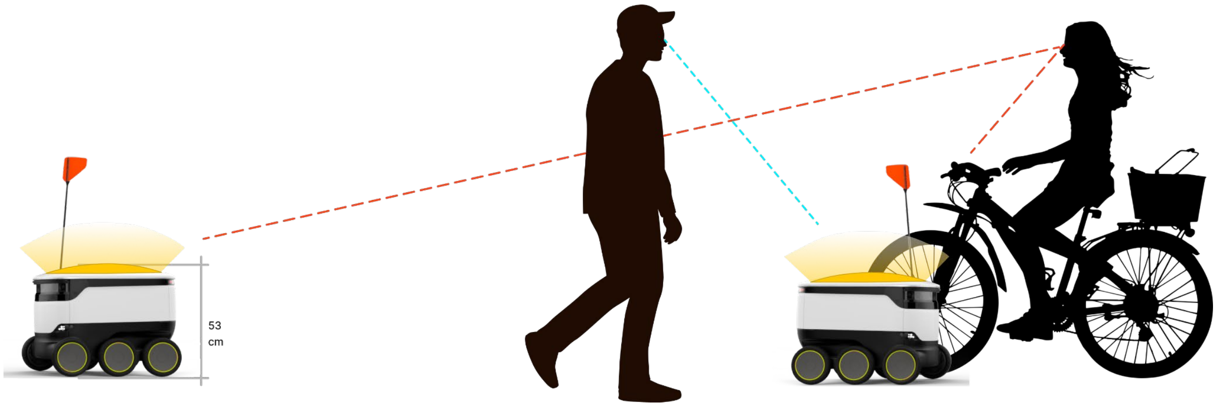

Figure 4 Indicators on the robot’s lid (source: author)

### 4.2.1 The Lights

To test the idea of having turning signals on the lid, two options are proposed (Figure 5):

1. Oblong "blinker" that runs along the edge of the lid.
2. Arrow-shaped light that changes its shape and blinks before turning.

The “blinker” design consists of a light that runs all around the lid's edge. Depending on what the robot intends to indicate, a specific area lights up. It can also be used, for example, to indicate from where to open the lid when the section at that spot lights up. The "arrow" design explores the idea that a robot could indicate its moving direction by using the symbol of an arrow. Possible further development of this direction is using symbols to indicate various occasions, such as the robot having an error or ongoing delivery steps.

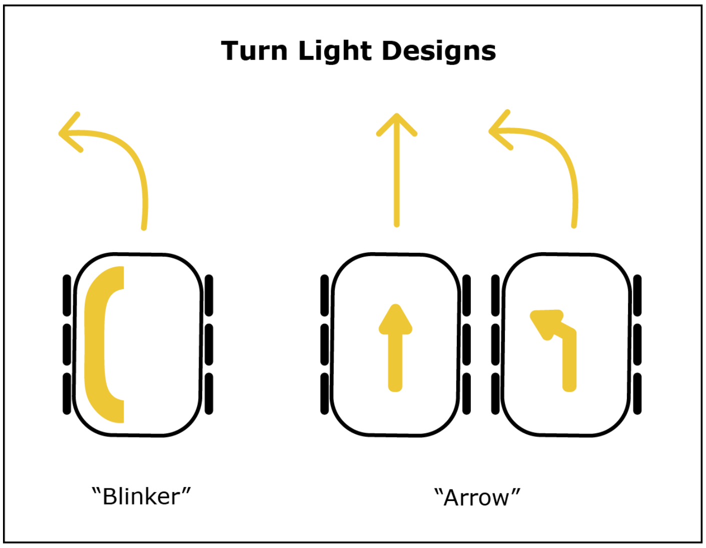

Figure 5 Turn light design ideas (source: author)

In addition to the turning signals, start- and stop-lights are proposed (Figure 6). These lights indicate when the robot intends to start and stop driving. They can also be used to indicate emergency stop cases where a robot is unable to proceed and needs to stop suddenly. All the lights are dimmable, and different colours, blinking patterns, and intensities can be used.

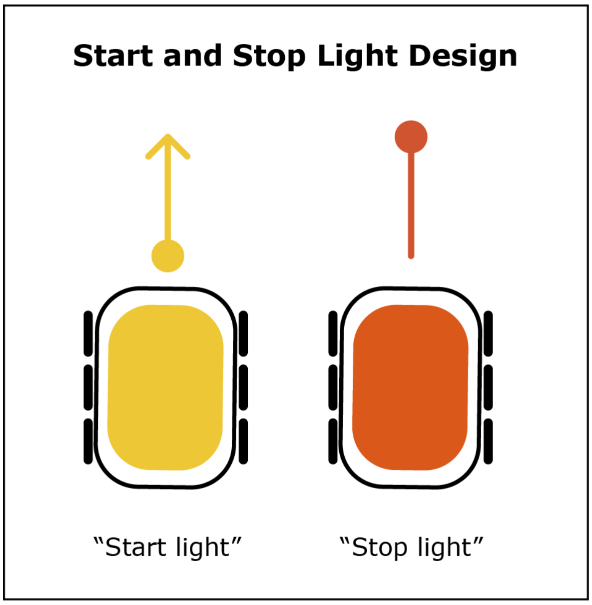

Figure 6 Start- and stop-lights (source: author)

### 4.2.2 The Sounds

As the robots are quite small, sometimes it might happen that just lights are not enough to indicate the intention to perform the manoeuvre. During the constructive design research, it is planned to test whether different sounds might add value to the interaction. The sounds planned to be tested include:

1. A "blinker" sound that resembles the classic car blinkers' ticking sound.
2. A warning sound that is rapid beeping.

### 4.2.3 The Body Language

Body language is a powerful communication tool. Humans intuitively interpret the intended direction of another individual through their body language. Similarly, robot movements can be used to let other sidewalk users know about the upcoming manoeuvre. The idea of using bogie movements for interaction is worth exploring. In this case, it is inquired whether raising and lowering the wheels attract attention and how people perceive such behaviour. The robot's rear or middle wheels will be raised approximately 5 centimetres and lowered again repeatedly.

## 4.4 Testing

### 4.4.1 Qualitative Approach

A qualitative approach is selected to test the hypotheses that better interaction design in the realms of visual signals, auditory feedback, displaying intended moving directions, and body language signals would benefit the ASR’s predictability. The current understanding of the problem is:

- ASRs show their intention to perform a manoeuvre insufficiently.
- Human perception of a robot's intentions is not consistently aligned with the robot's actual intentions.
- If ASRs showed their intentions more clearly, human perception would be more aligned with the intended actions.
- Consistent perception enhances pedestrian safety, reduces the risk of accidents, and fosters trust in ASRs.
- Clearer communication of intentions from ASRs can lead to smoother interactions between robots and pedestrians, promoting efficient navigation in urban environments and facilitating the integration of ASRs into daily routines.

The aim of the testing is to identify the elements and their combinations with the potential to improve predictability. Within the scope of this research, only the potential of these elements is evaluated. The design elements must also undergo testing and analysis through the collection of real-life quantitative data regarding their effectiveness. For instance, this could involve deploying two groups of robots, with one utilizing improved interactions and the other serving as the baseline. However, such testing currently exceeds the scope of this study.

Testing is divided into two phases. The first phase aims to gather users' thoughts and feelings and evaluate the effectiveness of individual design elements and their combinations. This phase serves to determine which elements exhibit sufficient potential or require further testing. Meanwhile, the second phase seeks to capture authentic real-life reactions to the use of combinations of interaction elements.

One reason for conducting tests in two phases is that testing all proposed components in real-life conditions would be time-consuming. Additionally, in the first phase, users' thoughts and feelings can be gathered, which is not feasible in the second phase. Figure 7 illustrates the testing plan, depicting the testable elements and testing phases.

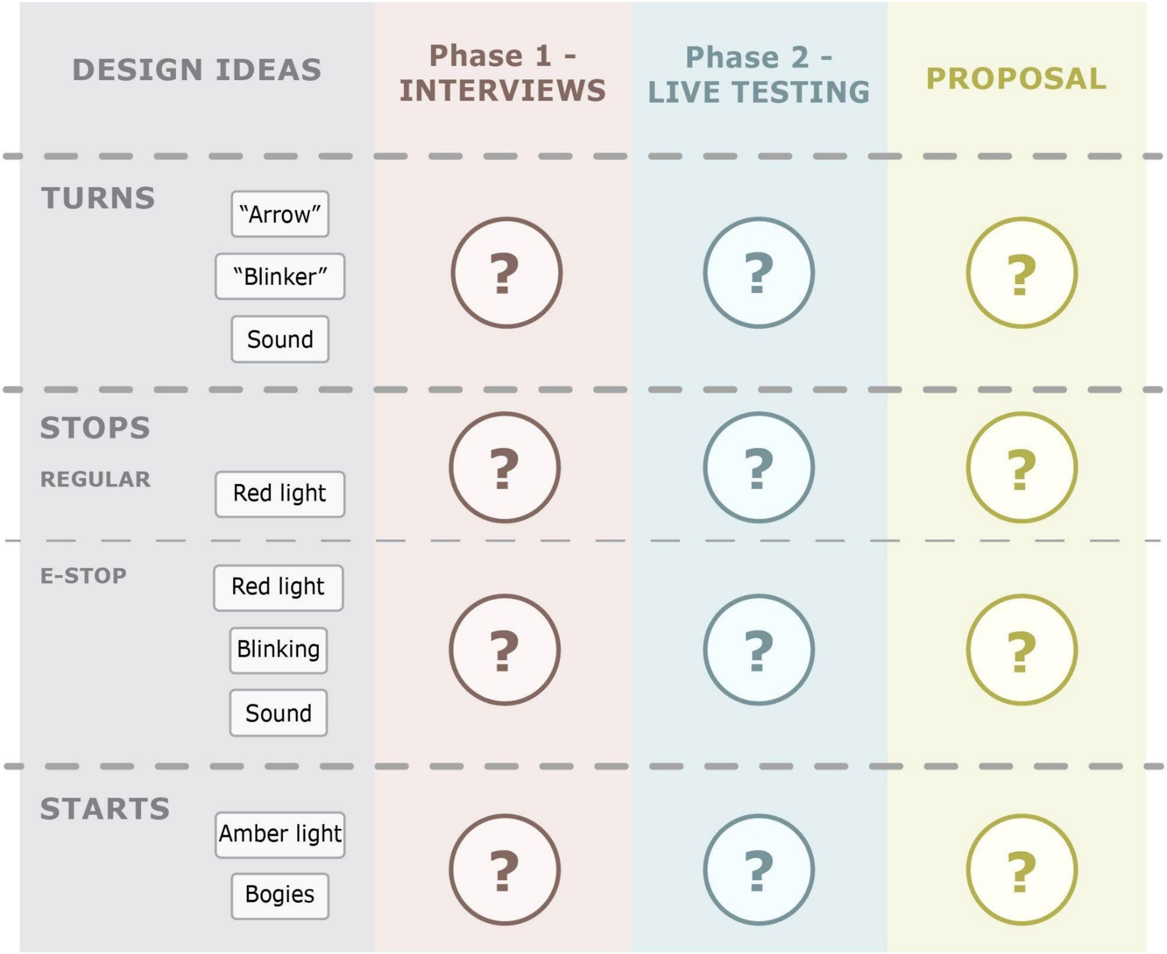

Figure 7 Testing plan (source: author)

In the first phase, a practical prototype is built to test the proposed hypotheses. This prototype not only serves to test the interaction design elements but also physically embodies the hypotheses. During this phase, the prototype is utilized to create video clips that combine various interaction elements. These video clips are subsequently presented to a sample of users to assess the comprehensibility of the interactions. The outcome of the first phase is confirmation of whether the proposed interaction elements would improve predictability and which proposed elements work the best.

The second phase aims to test the elements that passed the first round. In this phase, the same prototype is used for real-life testing with users—people walking and using micromobility vehicles on a sidewalk. During this phase, the prototype is operated with a remote controller, and the testable interaction features are employed in close proximity to members of the public. Authentic reactions are documented on video.

### 4.4.2 Prototype

The prototype is designed to closely resemble a standard robot to prevent people from immediately noticing its added features and scrutinizing it more closely than they typically would. Throughout testing, the robot must blend in seamlessly with other robots. The initial prototype is assembled using readily available solutions, such as an LED strip, a controller with a mobile app, and a portable power station, along with convenient materials like reused cardboard, tape, and kitchen foil (Figure 8). Keeping the initial prototype simple helps minimize costs and ensures a smooth workflow.

The prototype consists of:

1. Starship's delivery robot
2. Light module:
    a. LED-strip
    b. Controller with an app
    c. Foil for reflector
    d. The robot lid's plastic cover
2. Power source and adapter
3. Templates of the light shapes
4. The robot lid's plastic cover

To build the light module, a robot lid's plastic cover was cut smaller to fit under the top cover. Next, it was covered with foil to add a reflective feature. The LED strip and controller were taped on top of the foil. After that, cardboard light templates were made. Each light shape that needed to be tested was cut out of the cardboard, and foil was added to the underside of the template to enhance the light intensity. The light module was taped on top of the robot's lid for testing. Cardboard templates were taped underside of the top cover, and the top cover was taped onto the robot's lid.

White tape was used to maintain a clean and neat appearance, as the robot lid is white. The components of the prototype can be seen in Figure 9.

The design elements also include sounds. To add sound to the prototype, a Bluetooth speaker was placed inside the robot's basket and played sounds from a smartphone.

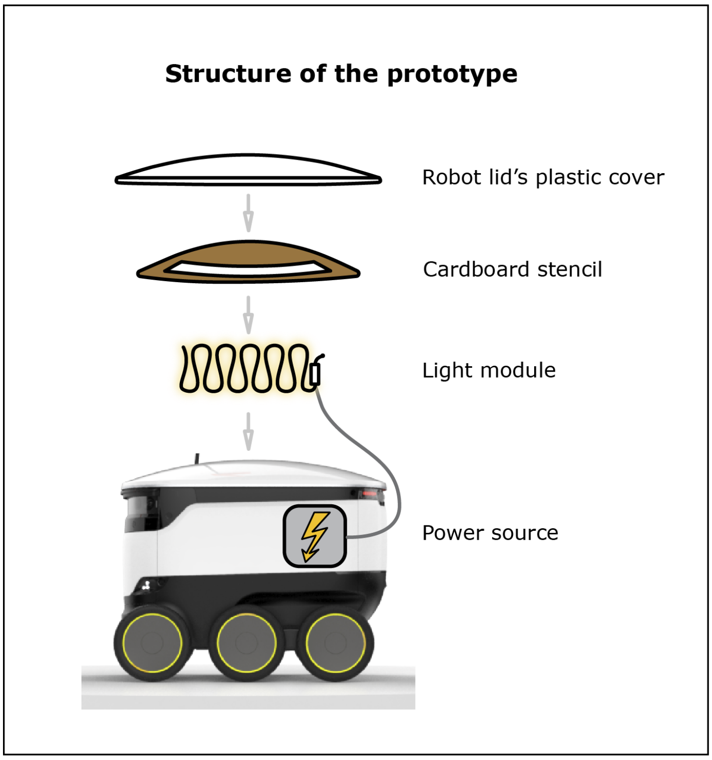

Figure 8 Assembly schema of the prototype, showing the components used and their arrangement (source: author)

Figure 9 Components of the prototype. From left to right: (1) the underside of a stencil; (2) the light module attached to the robot's lid; (3) the light module and stencil covered with the top cover. (source: author)

## 4.5 Phase 1 - Lab Tests

### 4.5.1 Sampling

The target population of the research can be defined as "any human using sidewalks." Obtaining a representative sample of this target population is complicated in this case, as the sampling frame is not available. Snowball sampling is used in the first phase of the research. Participants are asked to spread the word and ask friends and colleagues if they might be interested in participating in the testing. As the aim is to get preliminary feedback on the design ideas, it is not reasonable to put too much effort into finding the exact people to interview. The sample size in the first phase is 10-15 people. The facilitator asked her friends and co-workers to help spread the word.

In the second phase, accidental sampling is used. The prototype is taken to places where delivery robots normally operate to blend in. Another criterion is to find areas with a high volume of pedestrians and micromobility vehicle users. In Tallinn, one such place is Telliskivi Creative City and the surrounding areas. Since the testing will take place covertly, it is important to choose a location where this can be achieved, such as a spot with a place to hide so that passers-by do not connect the testing crew with the robot. The interaction must occur as naturally as possible to capture the authentic reactions of the people.

### 4.5.2 Videos

Semi-structured interviews are planned to confirm the hypotheses regarding enhancing human perception of the robot's intentions through improved interaction design. To test these hypotheses, the prototype was filmed in real-life conditions. The filming location was chosen to be a natural environment where both humans and robots move around. As manoeuvres are the research subjects, the location needs to allow for turning both left and right as well as starting and stopping, mimicking real-life situations as closely as possible. Additionally, the location is chosen for its proximity to the facilitator's home to avoid long travel times. The selected location is at the corner of Kunderi and Laulupeo streets in Tallinn.

The videos are simple, ranging from 10 to 18 seconds in length, and filmed by hand. They are divided into two groups: baseline and improved design.

**Baseline:**

1. Baseline turn: The robot drives straight and then turns to the left.
2. Baseline start: The robot is standing still and starts driving.
3. Baseline stop: The robot is driving straight and then stops.

**Improved design:**

1. **Robot turning:**
    a. Arrow turn: The robot drives straight with a straight arrow lit on the lid. A bent arrow starts blinking, and the robot turns in 3 seconds.
        i. Arrow turn with sound: Same interaction with the "tic-tic" sound.
    b. Blinker turn: The robot drives straight with a dimmed lid. A blinker on the side of the lid starts blinking, and the robot turns in 3 seconds.
        i. Blinker turn with sound: Same interaction with the "tic-tic" sound.
2. **Robot starting driving:**
    a. Improved start: The whole lid lights up, and the robot starts driving in a couple of seconds.
    b. Improved start with movements: The whole lid lights up, and the robot moves its wheels up and down. In a couple of seconds, the robot starts moving.
3. **Robot stopping:**
    a. Stop light: The lid lights up in red, and the robot stops in 2-3 seconds.
4. **Emergency stop:**
    a. E-stop blinks: The lid blinks rapidly in red, and the robot stops instantaneously.
    b. E-stop with sound: The lid blinks rapidly in red, a warning sound can be heard, and the robot stops immediately.

### 4.5.3 Interviews

The interviews will be semi-structured, meaning there is a list of core questions that will be asked, but there is also room for additional questions and discussions with the interviewees. One purpose of phase one is to evaluate potential interaction design elements, such as types of lights, movements, and sounds. Interviews will be conducted in either Estonian or English, as these are the languages the author can speak. The most valuable segments of the Estonian interviews will be translated into

English. The interviews will take place either at Starship's office or via video call. Before organizing the interviews, 1-2 test interviews will be conducted to ensure the structure is sufficient for gathering all the necessary information and to determine the duration of the interviews.

The interview is structured into 7 sections:

1. Introduction of the research
2. Asking whether the interviewee has any questions
3. Asking permission to record the interview
4. Asking whether the interviewee wishes to pick a nickname
5. Interview
6. Asking whether the interviewee has any additional thoughts
7. Concluding the interview and thanking the interviewee for participating.

A more detailed interview plan can be found in the appendices (Appendix 1).

During the interviews, videos of a Starship delivery robot transformed into a prototype driving on a street are shown to the interviewees. When the robot indicates its intention and just before it is about to perform the manoeuvre, the video is paused, and the interviewees are asked to predict what the robot will do next. Videos featuring both the baseline (current) interaction design and the proposed improved designs are shown to the interviewees. The responses are recorded in a spreadsheet (Appendix 2) in a simplified manner, indicating whether the interviewee's prediction was correct or not. Additionally, interviewees are asked to explain the reasoning behind their predictions. If possible, the interviewer takes notes during this process. After each interview, spare time is allocated to save and organize the audio files, notes, and the spreadsheet.

## 4.6 Phase 1 - Results

Twelve people were interviewed over the course of three days. As interviewees held opposing opinions on the matter, the results are rather inconclusive. However, the interviewees provided very interesting and insightful feedback. For example, one participant claimed that there were no interaction designs resembling cars and suggested looking towards car light interactions. Conversely, another interviewee stated that since the designs resembled what they were used to seeing on cars, everything was understandable.

Table 1 displays the results of predicting the manoeuvre based on the interaction. A limitation of these results is that some interviewees started seeking interaction cues only after watching 3 to 4 videos. Since the videos were played in the same order for all interviewees, it is possible that the results would have been different if played in a different order. Mirro wondered: “In the course of this test, I have a growing suspicion that I should watch those lights.”

Rollerskater pointed out: "In the previous video, I already connected that light with turning, and hereafter, I already know that blinking light on that edge means it’s going to turn that way." Jay also claimed to have learnt: "Now I noticed it. I’m learning from my mistakes." Some interviewees stated, they were looking at the back lights, thus they couldn’t see the lights on the lid. Speedy said: "Initially, my attention was on those lights down there, but much to my amazement, they didn’t blink."

| | Video 1 | Video 2 | Video 3 | Video 4 | Video 5 | Video 6 | Video 7 | Video 8 | Video 9 | Video 10 | Video 11 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Nickname** | **Baseline turn** | **Baseline stop** | **Baseline start** | **Blinker turn** | **Blinker sound** | **Arrow turn** | **Stop light** | **E-stop blinks** | **E-stop sound** | **New start** | **With bogies** |
| **Pipi** | No | No | No | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| **Rollerskater** | No | No | No | No | Yes | Yes | No | Yes | Yes | No | No |
| **Praneeth** | No | No | No | Yes | Yes | Yes | Yes | No | No | Yes | No |
| **Nupi** | No | No | No | No | Yes | Yes | Yes | No | Yes | Yes | Yes |
| **Pixel** | No | No | No | Yes | Yes | Yes | Yes | Yes | Yes | Yes | No |
| **Fisher** | No | No | No | Yes | Yes | Yes | No | No | Yes | No | No |
| **Paabu** | No | No | No | No | No | Yes | Yes | Yes | Yes | Yes | Yes |
| **Speedy** | No | No | No | No | No | Yes | Yes | No | Yes | No | Yes |
| **Villu R** | No | No | No | No | Yes | Yes | Yes | Yes | Yes | Yes | No |
| **Mirro** | No | No | No | No | No | Yes | Yes | No | No | Yes | Yes |
| **Jay** | No | No | No | No | Yes | Yes | Yes | Yes | Yes | No | No |
| **Pääsu** | No | No | No | Yes | Yes | Yes | Yes | No | Yes | No | Yes |

Table 1 Predictability of the manoeuvres performed in the videos (source: author)

### 4.6.1 Baseline Interaction

None of the interviewees could accurately predict the robot's intended manoeuvre based on its interaction. Many commented that the lack of information made it impossible to anticipate the robot's actions. As one interviewee, Rollerskater remarked: "Based on this information, I can’t even say that something is going to happen." Villu R assumed that the absence of signals indicated the robot had no intention to manoeuvre, stating, "As it does not signal anything, it keeps driving."

Some interviewees shared their experiences with the robots, highlighting their tendency to manoeuvre abruptly. Pipi, a regular customer in our service area, remarked, "They stop very unexpectedly. As I know quite a lot about those robots, I keep a longitudinal distance." Mirro echoed similar sentiments: "It can move at a steady pace and then suddenly stop." Pixel noted the abruptness of turns, stating, "Those turns could also be smoother. /…/ not that it drives straight and then suddenly turns 90 degrees." Villu R expressed concerns about sudden accelerations when leaving parking spots, saying, "[They] just out of nowhere are starting driving. /…/ When I'm walking, I'm looking at my phone and do not notice anything else. /…/ For me, it's the most important interaction when it's taking off." Pääsu recounted an incident while riding her bicycle: "I was riding my bicycle, and a robot drove by and cut me off. At that moment, it was not clear at all that it's intending to perform a manoeuvre."

The attitudes towards the robots varied among interviewees. Mirro described her encounters with robots: "It's like driving on a highway and seeing a bunny on the field." Pipi put it simply: "They are cute, and I like them." On the other hand, many interviewees stated the novelty of the robots had worn off for them. Praneeth, who moved to Tallinn 3 years ago and initially was very interested in the robots, remarked: "To be honest, I really don't concentrate on robots when I'm walking around because I've got used to them."

As interviewees struggled to interpret the robot's cues, they attempted to predict based on the information available to them. Many observed changes in the robot's speed. Praneeth expressed his perspective, stating, "I didn't see it slowing down to turn or stop." Paabu tried to assess the sound of the motors, suggesting, "Maybe something changed in the sound of the motors."

Some interviewees, who claimed to have little to no experience with the robots, speculated that before navigating around a blind corner, the robot should pause and cautiously proceed. Speedy, who had never encountered a sidewalk robot, theorized, "I think it might stop for a moment. It peaks around the corner /…/ and then proceeds driving."

The baseline lights on the back of the robot were deemed to be too small and insignificant. Nupi remarked, "Those lights are so small that on the street, I wouldn't look at them at all. It's like an LED strip on the background of a TV." Speedy stated, "It’s just a thin line." Praneeth elaborated, "I noticed them, but I didn’t pay attention. I think they are not doing anything. They are really small."

## 4.6.2 Proposed Turning Light Designs

### Placement of The Lights

Some interviewees opposed the lights being on the lid, as they are used to cars having lights on their rear side. Some later changed their minds. Initially, Mirro doubted the reasonability for having the lights on the lid: “If it [turn signal] was at the same place as cars have, and if it was orange, it would associate much more with the intent to perform a manoeuvre.” Later in the interview, she reconsidered: “Initially, it seemed to me that it would be logical to have turn signals placed analogously to cars. At the same time, when they are so low, I might not see them. Maybe I’m pushing my baby stroller. In that sense, on the roof, it’s quite clever, and it’s also a much bigger surface.”

Speedy pointed out that an adult person probably could see the lid better than lights close to the ground: “The taller someone is and the closer they are to the robot, the less they see those small lights.” Rollerskater stressed that lights needed to be visible from different distances: “When I’m approaching from behind, I’d prefer when there was some tail light, too. /…/ That lid light I only see when I’m already close, and it might be too late to react. /…/ It’s not rare that I’m going 35-40 kilometres per hour on skates.” Speedy offered a solution: “Rather could be both [lid and tail light] and work in sync.”

### The Material of the Lid

Some of those who could not predict turning signals correctly noted that the lid of the robot was so glossy and had many shadows on it. Rollerskater said: "This lid is shining and reflecting. /…/ During the daylight, with a white glossy lid and the light also being white, there’s not enough contrast. /…/ After rain, the road surface is also glistening, and there are shining spots and puddles everywhere. This light might not be visible."

Some said they mistook the turn signal with a reflection of the robot’s flag. Pääsu wondered: “It looks like something is blinking, but it might be a reflection.” It indicates that in the case of building a robot with lights on top of the lid, the material should be considered carefully. Many pointed out the lack of contrast between the white glossy lid and the yellowish-white light. More transparent and matte material would make it easier to see the lights. Different light conditions should be considered, though. In very bright sunlight, also, the lights should be very bright to be visible. But there also were more creative thoughts. Mirro was wondering: “Maybe it’s downloading an update, and then the light blinks.”

### Blinker Turn

Five out of 12 interviewees correctly predicted that the robot would turn right. When asked why they predicted this, all five people noted that there was a turn signal on the lid.

### Blinker Turn With Sound

The exact same video as previously was also shown with the blinker sound. Accompanied with the sound, 9 times out of 12, the intention was predicted correctly. Pipi emphasized: “I like it with the blinker sound more, but it should be thought through so it does not become annoying.” Rollerskater pointed out the similarities with automobiles: “The connection with cars is obvious. The same turn signal clicking sound.” Praneeth: “Sound is quite nice, and it brings your attention to it. /…/ The visual thing does not really force your attention.” Fisher was concerned about the visually impaired people: “For blind and visually impaired, that clicking sound does not mean anything? It sounded like a crosswalk clicking.” A few people compared it to bicycle bells. Nupi said she clearly prefers sound signals: “For me, the sound signals are utterly important. With bicycles, for example, it is so that when someone comes from the back, it’s a good shock. But if they ring the bell from farther away, I’m ready for them to come.” Pääsu, on the other hand, was strictly against all the sounds: “I absolutely do not want any sounds. It demands too much attention.”

### Arrow Turn

Based on the results of the interviews, the interaction with the arrow was more understandable than the blinker design. All the participants predicted the turning direction correctly with the arrow-shaped indicator. It was the only design that was predicted correctly by all the participants. Villu R claimed, “Arrow is much more intuitive. The blinker was like some reflection.” Fisher pointed out how easy it was to understand arrows: “Everybody understands arrows, even the kids, I think.”

When asked which one they prefer personally, the blinker or the arrow, the blinker was more likable. Praneeth put it that way: "I think I still prefer just light because it's more similar to what a vehicle would do. The other one [arrow] is like a street sign." Pääsu pointed out: "When it's on the side, I don't have to think. I'm not sure how much the position of the arrow is visible from the back." Pixel said she visually prefers the blinker: "It looks cooler when the edges are lit."

### 4.6.3 Stop Lights

#### Regular Stop Light

10 out of 12 participants predicted the stop light (brake warning light) correctly. In this interaction, the lid lights up in red, and the robot is gradually slowing down until it stops. Those who predicted correctly mentioned that, as it's red, they thought about cars also having red brake lights. Praneeth concluded, "Rationally, I'm guessing it just is going to stop. Because it is like red."

#### The Emergency Stop (e-stop)

E-stop was not that easy to predict. E-stop happens when the robot cannot proceed driving due to a detected threat. In the video, the robot was driving and suddenly stopped. At the same time, the lid started blinking in red. 6 out of 12 participants predicted correctly that the lid blinking in red must indicate some sort of error. Pipi asked, "Does it have some sort of error?" Paabu thought about safety reasons, saying, "It detected a threat from somewhere." Pixel pointed out the similarities with her motorcycle, stating, "When I just brake, then it's just a red light. /…/ When I suddenly brake, it starts blinking."

Those who did not predict correctly mostly thought it indicated that the robot had arrived at its destination. Nupi guessed that the robot was trying to say, "I arrived, now I'm staying here, do not run into me." Mirro thought it was connected to the delivery, suggesting, "Maybe it arrived to take the order."

**E-stop With Sound**

looks exactly the same as just e-stop, but a warning sound signal is added. It was predicted correctly 10 times out of 12. The sound was deemed to be warning but terrible. Mirro evaluated it as "aggressive. Unpleasant, I'd say." Fisher proposed that the sound is added for the visually impaired folks: "Maybe it's to indicate to the blind that something is in their way." Paabu wholesomely described it as "behaving like a little baby seagull who has lost its mother." Nupi stated, though, "Now it's certain that no one runs into it."

Two participants who did not guess correctly thought the robot was trying to indicate to the customer that it had arrived. Praneeth speculated, " It's done, and it's calling for a person."

## 4.6.4 Starting Driving

### Starting With the Big Lid Light

Seven out of 12 people predicted correctly that the lid lighting up means it starts doing something, and as it's standing still, it will probably start driving. Paabu guessed, "I suppose something is going to happen. As it was standing still, maybe it's starting to move." Pipi used the wording, "It starts itself," and Praneeth said, "It's warming up."

Some mentioned that if they see the lid lighting up, they would understand that something is going to happen, but if it already is lit up, they could not tell. Nupi thought, "Maybe I'd assume it's lit all the time." The concern was also about not understanding which way the robot intends to drive. For improvements, some interviewees gave advice to start moving by incrementally sneaking out from the parking spot. Nupi proposed, "So it does not come out at full speed /…/ but jerk-jerk-jerk and then drives."

### Starting Driving With Bogie Movements

Starting with bogie movements were predicted correctly 6 times out of 12. Those who could not predict mostly thought that the robot was suffering from a technical malfunction or being stuck on something. Pääsu assessed the situation, saying, "It does not look normal. Maybe it's broken." Fisher connected the behaviour with one he had seen before: "I have seen them shaking themselves like that in snow piles to get unstuck." Pixel thought, "Maybe it's parking on a brick." Some interviewees connected the behaviours to animals. Villu R described it as resembling a bull, and Nupi compared it to a horse. Pipi and Paabu thought the robot was dancing. Bogie movements were also considered threatening. Mirro felt uneasy, saying, "Pretty scary. It was a bit terrifying, I'd say."

Those who predicted correctly thought that as the robot started moving, it would keep moving. Paabu figured, "It gave a bit louder idea that now I'll start moving. /…/ As a pedestrian, it might be [useful]. Humans notice moving." Rollerskater thought bogie movements could be useful in case someone is concentrating on their smart device and does not see the lid lighting up: "In peripheral vision, it might work."

### 4.6.5 Conclusions of the Interviews

From the discussions with the participants, it appeared that some expect robots to be more considerate than they actually are. For example, a few interviewees thought that the robot would slow down and peek around the corner of the building before proceeding to drive. Many emphasized that currently, the robot's manoeuvres are abrupt and unpredictable and advised making manoeuvres smoother to give time for humans to react. Also, the placement of the lid lights was a concern for those moving fast on sidewalks. As Rollerskater put it, "Two elements that I want: manoeuvres should be slower and turn signals in back and front."

When it comes to robots making sounds, one interviewee was strictly against it as she did not want a machine to attract her attention for no reason. Other participants were not strictly against the idea of using sounds. They either did not see it as a benefit for themselves but also said they would not be bothered if there was a benefit for others. Some participants pointed out that for visually impaired people, sounds might be very useful. One participant wished a robot could make a sound when approaching from behind. The main concerns about sounds were:

1. Excessive use of sound might become annoying. Where and when to use sounds should be considered wisely.
2. Using sound during bedtime might disturb people in their homes.
3. Most people wear headphones on the streets and thus can't hear the sounds.

The interviews resulted in the selection of the elements for the next phase. Figure 10 provides a visual summary of the chosen elements.

1. **Turning:**
    a. Blinker light
    b. Blinker sound

Although some participants were not thrilled about using the sounds, only one was strictly against it. All but one participant admitted there might be some benefit in using sounds. In the further testing steps, it should be considered in which situations the sounds could be used.

2. **E-stop:**
    a. Blinking big light in red
    b. Warning sound

The regular stop will not be tested in the second phase, as it was mostly clear to the interviewees. The aim of the next phase is to determine whether the combination of blinking light and warning sound has any undesirable effects.

3. **Starting driving:**
    a. Lid lighting up
        i. No bogie movements
        ii. With bogie movements

Starting driving interactions received controversial and opposing feedback. Although the bogie movements were deemed to look like a malfunction or even terrifying, it also has some potential that needs to be tested in real-life situations.

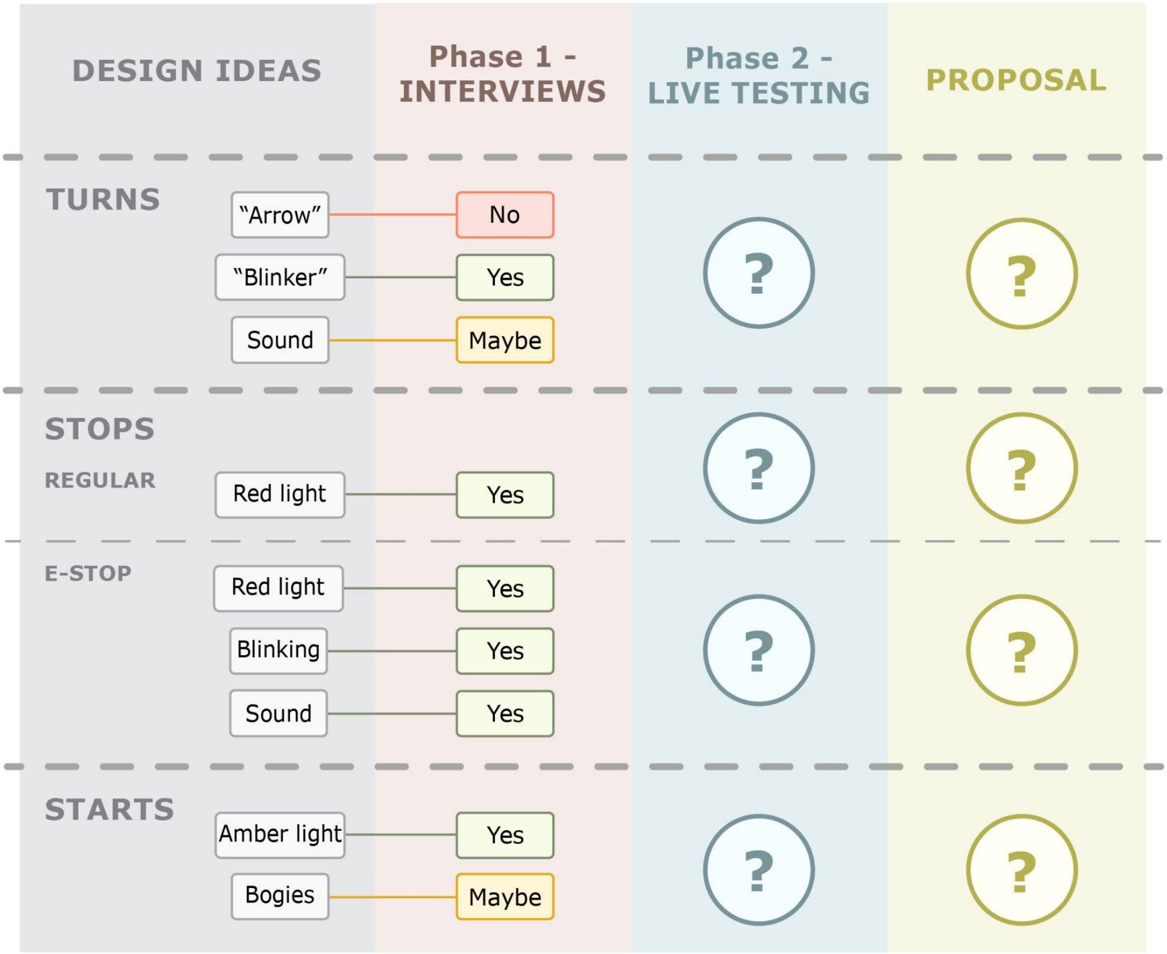

Figure 10 Results of testing phase 1 (source: author)

## 4.7 Phase 2 - Real-Life Experiment

### 4.7.1 Goal

The second phase of testing involves a real-life experiment. In this phase, the prototype is taken to an environment where robots and human sidewalk users naturally interact. The selected scenarios are played out, test results are documented and analyzed. The desired outcome of this phase is to gather enough authentic reactions from individuals moving near the prototype and observing the robot, indicating its intention to perform a manoeuvre. The reactions are analyzed, and based on the results, a proposal for interaction design is formulated.

### 4.7.2 Location

The experiment's location is on the sidewalk on Reisijate Street, between the Baltic railway station and Baltic Station Market, in Tallinn, Estonia. This location was selected because of its high pedestrian and micromobility traffic between the railway station and Telliskivi Street. Additionally, there is a terrace where interactions can be documented by filming.

### 4.7.3 Documenting

The experiment was documented through filming, chosen as the most accurate method for gathering and analyzing people’s reactions in real-life situations. Since the filming took place in a public space and did not involve the collection of sensitive personal data, permission from the ethics committee was not required. Given the nature of the testing, the author was unable to seek permission from the individuals passing by, as this would compromise the authenticity of their reactions if they were aware of being part of the experiment. It's important to note that the videos will not be published and will only be used for analyzing the effects of the robot’s behaviors on human sidewalk users.

### 4.7.4 Setup

The experiment required four people to set up. One person filmed the interactions with a drone, while another filmed with a camera from the terrace for documentation purposes. Additionally, one person drove the prototype around to control its behaviour, while another controlled the lights and sounds using smartphones. The experimenters attempted to appear as though they were simply hanging out and had no connection with the robot whatsoever.

## 4.8 Phase 2 - Results

### Turning

Most reactions to the robot blinking the blinker and using the blinker sound were simply acknowledging the robot, with individuals turning their heads and glancing briefly. There were no significant reactions beyond this behaviour. Given that the interaction is intended to be informative, this is considered an acceptable outcome. Similar to driving a car where another vehicle signals a turn, the action serves to inform and typically elicits no response beyond acknowledgement. The absence of startled reactions to the robot’s blinker sound suggests that the sound was appropriate for its purpose.

No adverse reactions were observed. Some individuals, likely tourists as they were seen dragging suitcases, responded to the robot by taking photos, while one gentleman attempted to race with the robot. Curiosity and playfulness when encountering a sidewalk robot are common and align with typical human behaviour.

### E-stop with sound

In this test, the robot was driving in front of pedestrians, moving in the same direction, and executed an emergency stop. It was only feasible to conduct this test with pedestrians, as abruptly stopping in front of micromobility riders felt too risky. From observations, it appears that residents of Tallinn are accustomed to the presence of robots and do not pay excessive attention to them while walking. Individuals engaged in conversations with companions often did not glance at the robots at all, instead leaning toward their companions. Some interviewees in Phase 1 also mentioned their lack of focus on the robots, a sentiment confirmed during the experiment.

The most common reaction to the robot's abrupt stop, accompanied by blinking lights and the warning sound, was a rapid deceleration and manoeuvring around the robot. Two individuals even made a warning hand gesture toward the robot. The majority simply bypassed the robot without giving it much consideration. Based on these reactions, it can be concluded that the e-stop with blinking red light and warning sound effectively captures the attention of human sidewalk users without eliciting exaggerated responses, although some annoyance was noted. Further testing is needed to determine the optimal timing and volume of sound usage.

### Starting driving

In this phase, both interactions, with and without bogie movements, were tested in real-life scenarios due to inconclusive interview results. Initially, the experiment was conducted without bogie movements. A young man, walking briskly and engrossed in typing on his smartphone, approached two robots parked at the sidewalk's edge. Despite the lid light illuminating, he failed to notice it. When the robot began slowly exiting the parking spot, he nearly collided with it, swerving around it at the last moment. This incident supported the suspicions of certain interviewees that individuals engrossed in their smartphones might overlook the lid lighting up. Given that individuals accustomed to the robots generally disregard them, heightened communication proves beneficial in such cases.

Testing with bogie movements yielded more promising results. Addressing the roughness of the bogie movements criticized during interviews, gentler movements were employed this time. The most common response to the robot rising on its tiptoes a few times was to garner attention from passersby, thus fulfilling the intended purpose. However, further consideration is necessary to determine which movement is sufficiently effective while remaining modest enough to avoid causing terror or misconceptions among individuals.

The test results are visualized in Figure 11.

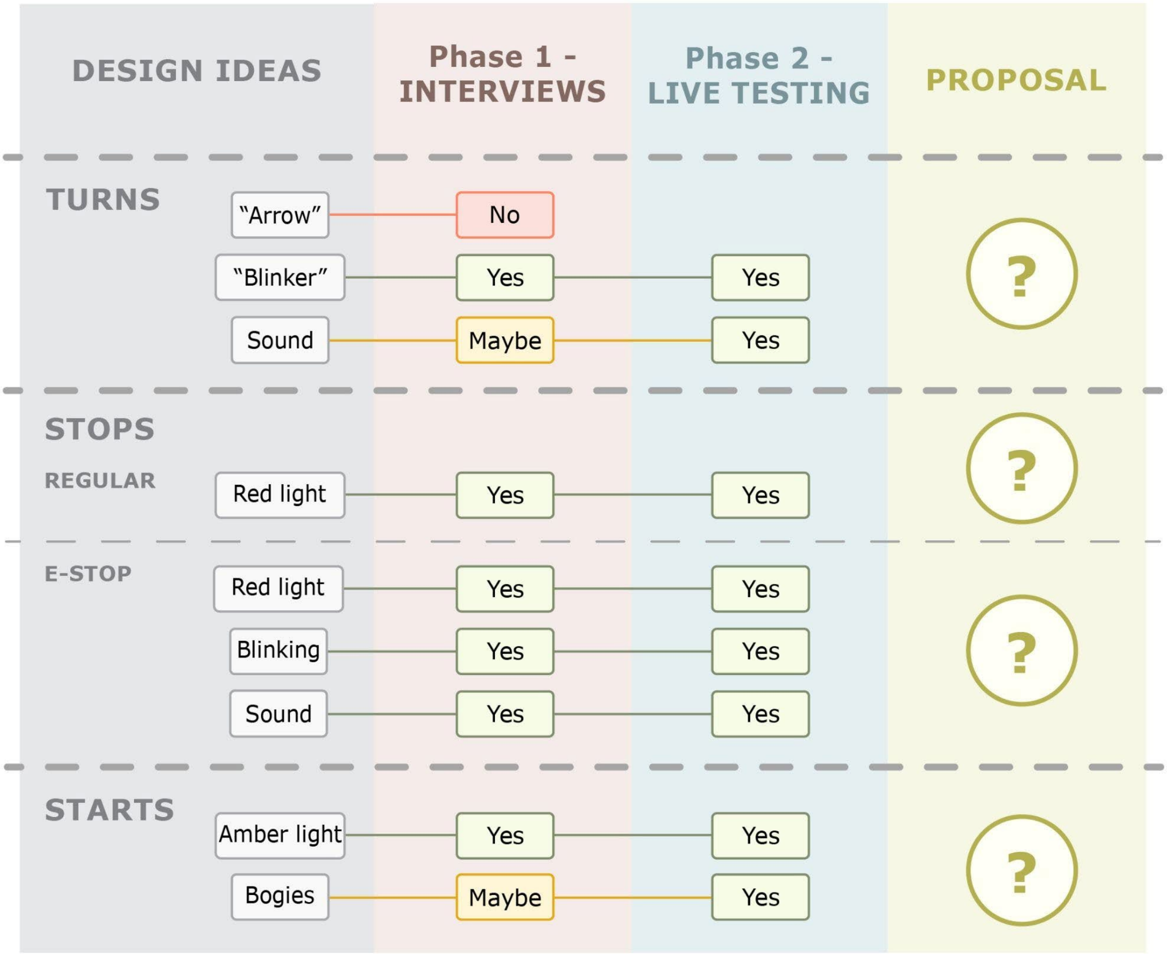

Figure 11 Results of testing phase 2 (source: author)

## 4.9 Proposal and Further Developments

The elements of the interaction design are chosen based on the interviews and the real-life experiment. Some of it requires further testing, as at this moment, it was not possible to get answers to all the questions.

The initial concept placed the turn signals on top of the lid. During the constructive design research, it was verified that lid lights are improving the interaction between humans and robots. At the same time, it was confirmed that the lights at the front and back sides of the robot are still needed for the faster-moving sidewalk users. Thus, the final proposal in this scope is to have lights both on the lid and also on the corners. When placed on the round corners, the lights are also visible from the sides, not only front and back. On the draft the placement of the lights is roughly marked with a red dashed line (Figure 12).

Figure 12 Proposed placement of the lights (source: author)

The exact placement and design should be worked out in cooperation with hardware engineering teams and product designers. The lights must fit with the overall design language and Starship’s image.

Also, it should be taken into account that manoeuvres are not the only matter that a robot needs to indicate. For instance, sometimes people do not understand whether the robot requires help or not, and communicating it would clear their doubts. There are also many touch points between humans and robots besides the interaction on the sidewalks. For example, Starship’s and partners’ employees have countless interactions with the robots every day. Their working tasks, from loading the orders to servicing the robots, involve a variety of ways to interact with the robots. Before finalizing the designs of the lights, all other potential interactions should be considered and involved in the design.

### 4.9.1 Proposed Turning Indication

For the turning indication, the following are proposed to be used:

1. Blinker light (Figure 13)
    a. On top of the lid
    b. On the round corners
2. Turn signal sound
    a. Only outside of bedtime
    b. Only in crowded places and when driving around corners
3. Body language
    a. Slowing down before turning
    b. Taking smoother corners than 90 degrees

Figure 13 Proposed placement of turning lights (source: author)

### 4.9.2 Proposed Stopping Indication

For the **regular stop,** it is proposed to use:

1. Big lid light in red (Figure 14)
2. Slowing down smoothly
3. No sound

For the **e-stop** it is proposed to use:

1. Big lid light blinking in red (Figure 14)
2. Warning sound - short beeping
    a. Only when moving humans are in the close proximity
    b. Outside sleeping hours

Figure 14 Proposed placement of stop lights (source: author)

### 4.9.3 Proposed Starting Indication

For starting driving, it is proposed to use:

1. Big lid light gradually lighting up in amber
2. Body language
    a. Moving the bogies while lighting up
    b. Starting driving gradually or incrementally
3. Turn signal before starting to drive if it’s needed to turn

The proposed interaction elements are visualized in Figure 15.

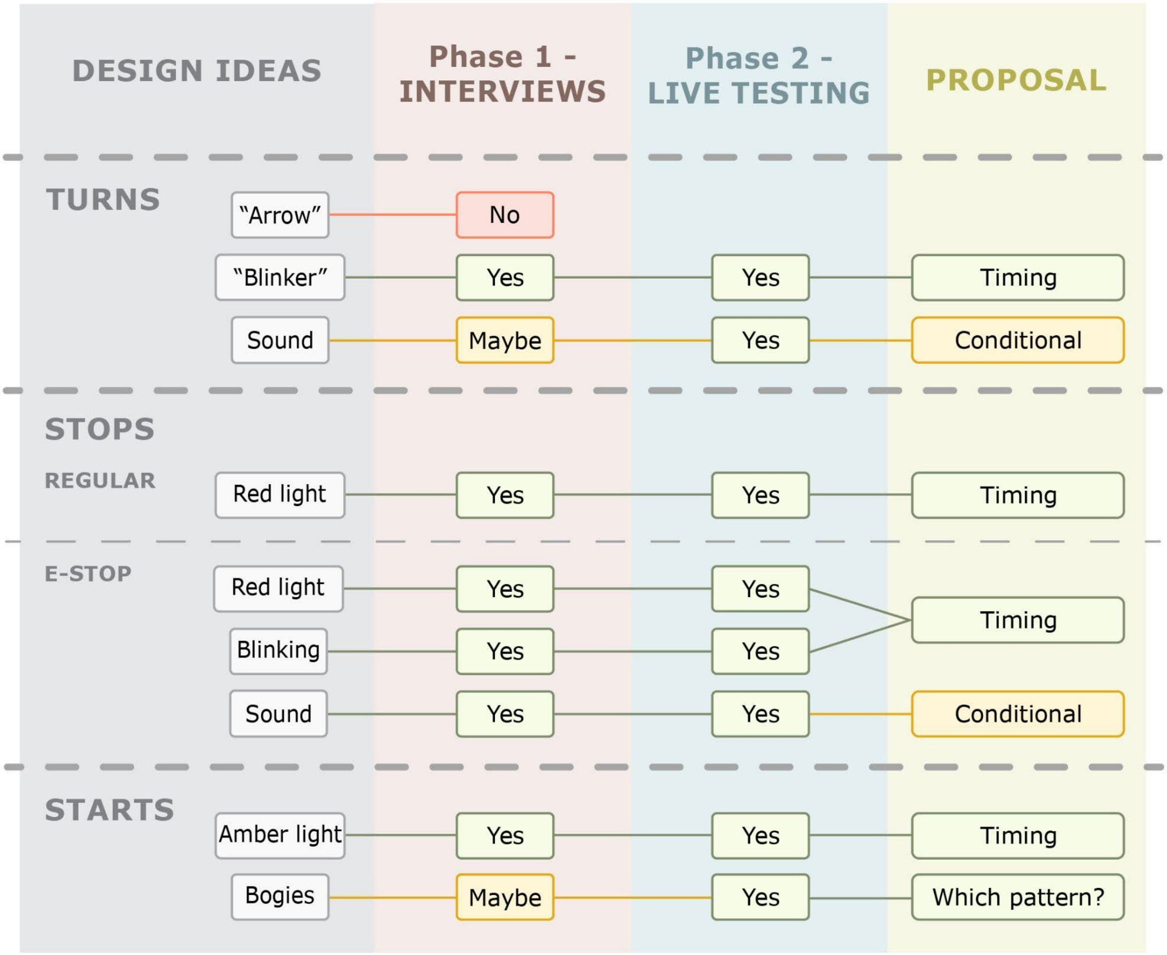

Figure 15 The proposal (source: author)

### 4.9.4 Further Developments

To further develop the design concept, it should be considered and tested:

1. How long before the manoeuvre should the lights be activated?
    a. Taking into account the braking distance of micromobility vehicles.
    b. Is the timing the same for turn signals, start signals, and braking signals?
2. How bright should the lights be?
    a. Tested at different times of the day to ensure visibility without blinding humans.
    b. Tested in different latitudes and climates to account for varying light conditions.
3. Which sound should be used, and how loud should it be?

    a. Considering different background noise environments.
    b. Considering times of the day.
4. What material is best for the lid lights?
    a. Ensuring visibility.
    b. Avoiding excessive reflections and glare.
    c. Considering factors such as durability, cost, and maintenance.

### 4.9.5 Adaption for the Current Hardware

As developing a new model of the robot is both expensive and time-consuming, it's important to consider how the proposed changes can be adapted to the current hardware. While adding new lights may not be feasible, there are still adjustments that can be made:

1. Turns:
    a. Gradually slowing down before turning.
    b. Avoid sharp 90-degree turns to mimic human walking patterns.
    c. Experimenting with different turn signal patterns for better visibility.
    d. Combining the turn signal with the blinker sound.
2. Stops:
    a. Regular stop:
        i. Smoothly slowing down
        ii. Using existing lights to indicate the intention to stop.
    b. E-stop:
        i. Blinking the existing lights.
        ii. Adding a warning sound.
3. Starting driving:
    a. Activating the bogies before moving.
    b. Incrementally leaving the parking spot.
    c. Blinking the existing lights before starting to drive.

During the process of refining the current interaction design, several important tests can provide insights for the new robot model. For example, testing the timing of slowing down or activating signals before manoeuvres can be beneficial. Additionally, reconsidering the principles of sidewalk mapping can help make turns smoother and easier to understand for pedestrians.

# 5 DISCUSSION

The research answers the question, “How to improve autonomous sidewalk robot’s predictability among sidewalk users?” By employing a practical prototype, this study explores the subject and proposes the use of various interaction design elements and their combinations. Visual signals, such as LED lights, assist human sidewalk users in better predicting a robot's intentions. Combining visual signals with auditory cues enhances perceptibility, particularly in situations where humans may not be fully attentive to a sidewalk robot. Additionally, movement helps attract human attention, which is potentially useful in indicating the intention to start moving.

## 5.1 Potential Further Developments

As the research concentrated on the potential of individual elements, the concept needed to be developed further. The proposal of the study identifies the most prospective avenues. The timing of using the lights needs to be considered, taking into account the braking distances of micromobility vehicles, and tested in real-life situations by implementing the design elements into the robots. It allows us to gather quantitative data about the usefulness of the element and when to use it. The brightness of the lights also needs to be tested at different times of the day, ensuring visibility in bright conditions without blinding them in the dark.

The sounds require comprehensive sound design to find the correct volumes for different background noises and the times of the day. As in this research the sounds used were chosen based on availability, the author does not recommend simply using the same sounds for future implementations.

The lid's material proved challenging due to its glossiness, so the mechanical engineers needed to explore further which technical solutions to use. If the light source is placed underneath the top cover, the material needs to ensure enough visibility and avoid excessive reflections and glare. Also, factors like power consumption, durability, cost, and maintenance need to be taken into account.

## 5.2 Contribution to the Field

This thesis opens up the topic of predictability of autonomous sidewalk robots, a subject that holds potential benefits for various stakeholders with diverse interests. Communities, such as local residents, urban activists and NGOs, benefit from better predictability by enhancing the safety of the sidewalks. Safer sidewalks create a pleasant atmosphere for active transport and sojourning while promoting walkability. Through better predictability, delivery times may potentially be shortened, which benefits the customers, companies providing the service and their partners. Improved predictability also promotes acceptability amongst the public and local governments, which is crucial for deploying autonomous robots to new service areas. As many countries do not have the legislation yet, the smooth coexistence of sidewalk robots and humans in other countries may encourage them to approve companies to conduct pilot studies in their cities. Also, research in autonomous sidewalk robots' predictability enchantments is one step forward for creating a coherent and socially aligned group of sidewalk users.

# 6 REFERENCES

[1] "Starship Technologies: Autonomous robot delivery," Starship Technologies: Autonomous robot delivery. Accessed: Feb. 02, 2024. [Online]. Available: https://www.starship.xyz/

[2] "Emotional attachment to robots could affect outcome on battlefield," UW News. Accessed: May 18, 2024. [Online]. Available: https://www.washington.edu/news/2013/09/17/emotional-attachment-to-robots-could-affect-outcome-on-battlefield/

[3] M. Gross, *The urbanisation of our species*, vol. 26. 2016. Accessed: Feb. 02, 2024. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S0960982216313926

[4] U. Nations, "68% of the world population projected to live in urban areas by 2050, says UN," United Nations. Accessed: Feb. 02, 2024. [Online]. Available: https://www.un.org/uk/desa/68-world-population-projected-live-urban-areas-2050-says-un

[5] "Global status report on physical activity 2022," World Health Organization, Geneva, 2022. Accessed: Feb. 02, 2024. [Online]. Available: https://www.who.int/publications-detail-redirect/9789240059153

[6] "Improving the Quality of Walking and Cycling in Cities," OECD Publishing, Paris, Text, Feb. 2024.

[7] C. Perez, "Technological revolutions and techno-economic paradigms".

[8] M. Kiba-Janiak, J. Marcinkowski, A. Jagoda, and A. Skowrońska, "Sustainable last mile delivery on e-commerce market in cities from the perspective of various stakeholders. Literature review," *Sustainable Cities and Society*, vol. 71, p. 102984, Aug. 2021, doi: 10.1016/j.scs.2021.102984.

[9] J. J. Faria, S. Krause, and J. Krause, "Collective behavior in road crossing pedestrians: the role of social information," *Behavioral Ecology*, vol. 21, no. 6, pp. 1236–1242, Nov. 2010, doi: 10.1093/beheco/arq141.

[10] U. Hasson and C. D. Frith, "Mirroring and beyond: coupled dynamics as a generalized framework for modelling social interactions," *Philos Trans R Soc Lond B Biol Sci*, vol. 371, no. 1693, p. 20150366, May 2016, doi: 10.1098/rstb.2015.0366.

[11] S. A. G. Wensveen, *Constructive design research*. Eindhoven: Technische Universiteit Eindhoven, 2018.

[12] A. Bang, P. Krogh, M. Ludvigsen, and T. Markussen, *The Role of Hypothesis in Constructive Design Research*. 2012.

[13] R. Singh, "Factors Affecting Walkability of Neighborhoods," *Procedia - Social and Behavioral Sciences*, vol. 216, pp. 643–654, Jan. 2016, doi: 10.1016/j.sbspro.2015.12.048.

[14] "Pedestrian Safety, Urban Space and Health," Text, Oct. 2015.

[15] J. Gehl, *Cities for People*. Washington DC: Island Press, 2010.

[16] J. Westenhöfer, E. Nouri, M. Reschke, F. Seebach, and J. Buchcik, "Walkability and urban built environments—a systematic review of health impact assessments (HIA)," *BMC Public Health*, vol. 23, Mar. 2023, doi: 10.1186/s12889-023-15394-4.

[17] "Safer Micromobility," International Transport Forum, Mar. 2024.

[18] O. James, J. Swiderski, J. Hicks, D. C. Teoman, and R. Buehler, "Pedestrians and E-Scooters: An Initial Look at E-Scooter Parking and Perceptions by Riders and Non-Riders," *Sustainability*, vol. 11, p. 5591, Oct. 2019, doi: 10.3390/su11205591.

[19] "Paris e-scooter ban: What are the rules and risks across Europe?," euronews. Accessed: Apr. 15, 2024. [Online]. Available: https://www.euronews.com/next/2023/09/01/electric-scooters-what-are-the-rules-across-europe-and-where-are-injuries-highest

[20] B. Green, *The Smart Enough City*. The MIT Press, 2020. Accessed: Feb. 15, 2024. [Online]. Available: https://smartenoughcity.mitpress.mit.edu/

[21] D. B. Lee, L. A. Klein, and G. Camus, "Induced Traffic and Induced Demand," *Transportation Research Record*, vol. 1659, no. 1, pp. 68–75, Jan. 1999, doi: 10.3141/1659-09.

[22] "The Story of the Intel® 4004," Intel. Accessed: May 13, 2024. [Online]. Available: https://www.intel.com/content/www/us/en/history/museum-story-of-intel-4004.html

[23] T. Bosona, "Urban Freight Last Mile Logistics—Challenges and Opportunities to Improve Sustainability: A Literature Review," *Sustainability*, vol. 12, no. 21, Art. no. 21, Jan. 2020, doi: 10.3390/su12218769.

[24] "J3016_202104: Taxonomy and Definitions for Terms Related to Driving Automation Systems for On-Road Motor Vehicles - SAE International." Accessed: Apr. 27, 2024. [Online]. Available: https://www.sae.org/standards/content/j3016_202104

[25] "Delivery Robots for Everyone!" Accessed: May 15, 2024. [Online]. Available: https://www.kiwibot.com/

[26] "Meet Scout," US About Amazon. Accessed: May 15, 2024. [Online]. Available: https://www.aboutamazon.com/news/transportation/meet-scout

[27] "Yandex — Company news — Yandex Starts Testing Autonomous Delivery Robot," Yandex. Accessed: May 15, 2024. [Online]. Available:

https://yandex.com/company/press_center/press_releases/2019/2019-11-07

[28] "SPF | Police Life | Police Patrol Robots in Action," Singapore Police Force. Accessed: May 14, 2024. [Online]. Available: http://www.police.gov.sg/Media-Room/Police-Life/2023/06/Police-Patrol-Robots-in-Action

[29] "MTI | Free Full-Text | Sharing the Sidewalk: Observing Delivery Robot Interactions with Pedestrians during a Pilot in Pittsburgh, PA." Accessed: Jan. 31, 2024. [Online]. Available: https://www.mdpi.com/2414-4088/7/5/53

[30] A. Dobrosovestnova, I. Schwaninger, and A. Weiss, "With a Little Help of Humans. An Exploratory Study of Delivery Robots Stuck in Snow," presented at the #PLACEHOLDER_PARENT_METADATA_VALUE#, Sep. 2022, pp. 1023–1029. doi: 10.1109/RO-MAN53752.2022.9900588.

[31] H. R. M. Pelikan, S. Reeves, and M. N. Cantarutti, "Encountering Autonomous Robots on Public Streets," in *Proceedings of the 2024 ACM/IEEE International Conference on Human-Robot Interaction*, in HRI '24. New York, NY, USA: Association for Computing Machinery, märts 2024, pp. 561–571. doi: 10.1145/3610977.3634936.

[32] S. R. Gehrke, C. D. Phair, B. J. Russo, and E. J. Smaglik, "Observed sidewalk autonomous delivery robot interactions with pedestrians and bicyclists," *Transportation Research Interdisciplinary Perspectives*, vol. 18, p. 100789, Mar. 2023, doi: 10.1016/j.trip.2023.100789.

[33] "National Traffic and Motor Vehicle Safety Act | US Regulations, 1966 | Britannica." Accessed: May 14, 2024. [Online]. Available: https://www.britannica.com/technology/automobile/History-of-the-automobile

[34] ERR, "Estonian government supports allowing robot vehicles on streets," ERR. Accessed: May 14, 2024. [Online]. Available: https://news.err.ee/588505/estonian-government-supports-allowing-robot-vehicles-on-streets

[35] "Delivery robots are coming. The law isn't ready - Tech Monitor." Accessed: May 14, 2024. [Online]. Available: https://techmonitor.ai/technology/ai-and-automation/delivery-robots-coming-law-not-ready

[36] "Small transport robots received more detailed technical requirements," Traficom. Accessed: May 14, 2024. [Online]. Available: https://www.traficom.fi/en/news/small-transport-robots-received-more-detailed-technical-requirements

[37] "Road Traffic Act–Riigi Teataja." Accessed: May 14, 2024. [Online]. Available: https://www.riigiteataja.ee/en/eli/ee/523012024001/consolide/current

[38] "Vehicle categories," Traficom. Accessed: May 14, 2024. [Online]. Available: https://www.traficom.fi/en/transport/road/vehicle-categories

[39] "'More dangerous than ever': Blind and low vision pedestrians fear for their safety as e-scooters and bikes take over | Vision Australia. Blindness and low vision services." Accessed: Apr. 26, 2024. [Online]. Available: https://visionaustralia.org/news/2021-10-14/WCD-2021

[40] "Dangerous driving by e-scooter users 'represents serious danger to visually impaired' - foundation - The Malta Independent." Accessed: Apr. 26, 2024. [Online]. Available: httpss://www.independent.com.mt/articles/2022-08-10/local-news/Dangerous-driving-by-e-scooters-represents-serious-danger-to-visually-impaired-foundation-6736245108

[41] "Guide dogs taught to deal with delivery robots." Accessed: Apr. 26, 2024. [Online]. Available: https://www.bbc.com/news/articles/cv2jn2wv84mo

[42] "Making AI delivery robots disability-friendly and 'cautious pedestrians,'" May 30, 2023. Accessed: Apr. 26, 2024. [Online]. Available: https://www.bbc.com/news/disability-65719649

[43] "Falls and Fractures in Older Adults: Causes and Prevention," National Institute on Aging. Accessed: May 14, 2024. [Online]. Available: https://www.nia.nih.gov/health/falls-and-falls-prevention/falls-and-fractures-older-adults-causes-and-prevention

[44] P. Bartha, "Analogy and Analogical Reasoning," in *The Stanford Encyclopedia of Philosophy*, Summer 2022., E. N. Zalta, Ed., Metaphysics Research Lab, Stanford University, 2022. Accessed: May 15, 2024. [Online]. Available: https://plato.stanford.edu/archives/sum2022/entries/reasoning-analogy/

[45] "The code for cuteness | BBC Earth." Accessed: May 15, 2024. [Online]. Available: https://www.bbcearth.com/news/the-code-for-cuteness

[46] "Three laws of robotics | Definition, Isaac Asimov, & Facts | Britannica." Accessed: May 14, 2024. [Online]. Available: https://www.britannica.com/topic/Three-Laws-of-Robotics

[47] "bogie." Accessed: Apr. 27, 2024. [Online]. Available: https://dictionary.cambridge.org/dictionary/english/bogie

# 7 APPENDICES

## Appendix 1 Interview Plan

1. Intro: "Hello, and thank you for coming to this interview. I am Maria, and I'm a student at Tallinn University of Technology and I work at Starship as a manual tester. I'm writing my master's thesis about the topic of "how to share sidewalks with autonomous robots?"
   The aim of the interview is to evaluate the Starship robot's ability to indicate its intention to perform a manoeuvre. I'm going to show you videos of a robot 6E7 driving on a sidewalk. I stop the video and ask you to predict what the robot will do next. There are no wrong or right answers; take it as a game. Do you have any questions?"

2. Possible discussion and answering the questions.

3. Asking permission to record the interview. "Can I record the interview? The audio of you speaking is not going to be presented anywhere. Only your statements might be presented in a written form."

4. Asking to pick a nickname

5. Interview
   a. Have you ever met a Starship robot on the street?
   b. Describe how it happened
   c. Was it clear to you when the robot wanted to turn, stop or start driving?
   d. *Showing the video **"Baseline turn"** and pausing before the manoeuvre*
      i. What do you think the robot is doing next?
      ii. Why do you think so?
      *Showing the end of the video*
   e. *Showing the video **"Baseline stop"** and pausing before the manoeuvre*
      i. What do you think the robot is doing next?
      ii. Why do you think so?
      *Showing the end of the video*

f. *Showing the video* ***"Baseline start"*** *and pausing before the manoeuvre*
    i. What do you think the robot is doing next?
    ii. Why do you think so?
    *Showing the end of the video*
g. *Showing the video* ***"Blinker turn"*** *and pausing before the manoeuvre*
    i. What do you think the robot is doing next?
    ii. Why do you think so?
    *Showing the end of the video*
h. *Showing the video* ***"Blinker turn with sound"***
    i. Do you notice what was different in these videos?
    ii. Do you think sound improved the interaction for you?
    iii. Would you prefer the interaction with or without the sound?
*i.* *Showing the video* ***"Arrow turn"*** *and pausing before the manoeuvre*
    *i.* What do you think the robot is doing next?
    *ii.* Why do you think so?
    *Showing the end of the video*
j. *Showing the video* ***"Stop light"*** *and pausing before the manoeuvre*
    i. What do you think the robot is doing next?
    ii. Why do you think so?
    *Showing the end of the video*
k. *Showing the video* ***"E-stop blinks"***
    i. What do you think happened in this video?
    ii. Why do you think so?
l. *Showing the video* ***"E-stop with sound"***
    i. Do you notice what was different in these videos?
    ii. Do you think sound improved the interaction for you?
    iii. Would you prefer the interaction with or without the sound?
m. *Showing the video* ***"New Start"*** *and pausing before the manoeuvre*
    i. What do you think the robot is doing next?
    ii. Why do you think so?
    iii. Do you think it was more clear than in the baseline video that the robot is going to drive away?
    *Showing the end of the video*
n. *Showing the video* ***"New Start with movements"***
    i. Do you notice what was different in these videos?
    ii. Do you think movements improved the interaction for you?

        iii. Would you prefer the interaction with or without the movements?
    o. Looking back at all the videos, do you prefer a design with blinkers or with arrows?
    p. Do you prefer sound or no sound?
6. Asking whether the interviewee has any additional thoughts
7. Concluding the interview and thanking the interviewee for coming.

## Appendix 2 Interview Form

| | Video 1 | Video 2 | Video 3 | Video 4 | Video 5 | Video 6 | Video 7 | Video 8 | Video 9 | Video 10 | Video 11 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Nickname** | **Baseline turn** | **Baseline stop** | **Baseline start** | **Blinker turn** | **Blinker sound** | **Arrow turn** | **Stop light** | **E-stop blinks** | **E-stop sound** | **New start** | **With bogies** |
| | | | | | | | | | | | |
| | | | | | | | | | | | |
| | | | | | | | | | | | |
| | | | | | | | | | | | |
| | | | | | | | | | | | |
| | | | | | | | | | | | |
| | | | | | | | | | | | |
| | | | | | | | | | | | |
| | | | | | | | | | | | |
| | | | | | | | | | | | |
| | | | | | | | | | | | |
| | | | | | | | | | | | |

# 8 KOKKUVÕTE

Linnadest on saanud inimeste peamine elupaik, mis kujundab kuidas me elame, töötame ja liigume. Koos linnade kasvava elanikkonnaga suureneb ka kõnniteid kasutavate inimeste arv. Kõndimine ja muud aktiivsed liikumisviisid, mida kõnniteedel tihti rakendatakse, on tervisele mitmekülgselt kasulikud, soodustades head füüsilist vormi ja vähendades krooniliste haiguste riski. Pidevalt muutuvasse linnakeskkonda on aga lisandunud uued tegurid, nagu elektritõukerattad ja autonoomsed kõnniteerobotid.

Kuigi autonoomsete robotite ilmumine linnapilti on avalikkuse poolt üldiselt hästi vastu võetud, pole see kulgenud tõrgeteta. Kuna robotite sotsiaalne käitumine erineb inimeste omast ja nende interaktsiooni funktsioonid on limiteeritud, on ilmnenud tõsiasi, et robotite võimetus selgelt väljendada oma kavatsusi põhjustab arusaamatusi ja ohtlikke olukordi inimeste ja robotite vahelises interaktsioonis.

Käesolevas töös uuritakse võimalusi parandada läbi interaktsioonidisaini muudatuste kõnniteerobotite ettearvatavust kõnniteid kasutavate inimeste hulgas. Eesmärk on tuvastada iteratiivse prototüüpimise, kasutajate tagasiside ja reaalses keskkonnas läbi viidud eksperimentide kaudu interaktsiooni elemendid, mis parandavad robotite võimekust väljendada kavatsust. Selle uurimistöö mahus pakutakse välja ja testitakse üksikuid interaktsiooni elemente ning nende kombinatsioone.

Uurimuse tulemused viitavad, et teatud visuaalsete ja auditiivsete vihjete ning liikumismustrite abil on potentsiaalselt võimalik parandada jalakäijate arusaamist robotite kavatsustest ning suurendada turvalisust. Praktiline uurimistöö pakub välja, millised elemendid ja nende kombinatsioonid on suurima potentsiaaliga ning kuidas neid rakendada Starshipi pakirobotitel.