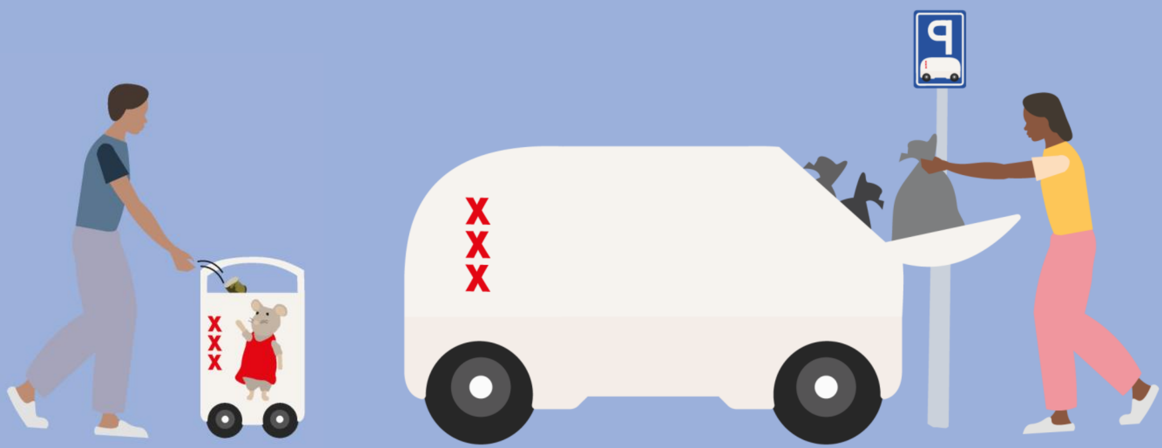
Robots for a Cleaner Amsterdam

Roadmapping Waste Relationships for the Next Decade



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Preface

I would like to express my gratitude to my coaching team for their support and guidance throughout this complex project. In particular, I am grateful to my mentor, Jered Vroon, for the valuable Tuesday sessions where I received insightful feedback and was encouraged to find answers within myself. Your guidance enabled me to develop a deeper understanding of the subject matter. I would also like to thank my chair, Sjoerd van Dommelen, for constantly challenging me to think beyond my initial ideas and encouraging me to explore new perspectives.

I would like to acknowledge the contributions of Antina Snijders, Ruben van Thal, and Thijs Turel for their valuable feedback and engaging discussions, which have greatly enriched my thesis.

Finally, I am immensely grateful to my family and friends for their continued support. Their willingness to read and provide feedback on my thesis, as well as engage in endless discussions about my project, has been invaluable in shaping my ideas and gaining new insights.

Executive Summary

As current cleaning targets are not achieved, Amsterdam requested to explore the potential for robots to contribute to a cleaner city. This thesis focused on exploring how a robot could contribute. A contextual analysis, reviewing literature and municipal documents, showed an increasing need for improved waste management efficiency in response to Amsterdam's growth, increasing tourism and sustainability goals. However, increasing labour shortages and demographic ageing make it difficult to rely solely on additional human labour in the coming years.

To further analyse the context, employees of department Schoon were accompanied and interviewed. Six key values were identified contributing to job satisfaction - safeguarding these is crucial for successful robot implementation, including freedom and dislike of heavy work. Challenges were also identified, including labour shortages and reduced efficiency.

To determine where a robot could add value, three main waste problems in Amsterdam were identified and analysed. Inefficient waste management and littering behaviour were often the cause. To understand this behaviour, key influencing factors were identified and used in the analysis and thesis.

Furthermore, by analysing key factors of waste management behaviour, it was found that a cleaning robot can potentially trigger motivators for littering behaviour, suggesting that the robot's task influences waste management behaviour. Furthermore, when identifying factors influencing HRI, it was found that rewarding interactions can motivate proper behaviour, suggesting that robots can contribute to a cleaner environment without having to clean.

Based on the findings, specific requirements and a design vision for the robot were established, emphasising promoting proper waste management behaviour, ownership and waste management efficiency. To communicate the vision to the municipality, two concepts were developed, the Mobile Robot Bin and Mobile Robot Container. The Robot Bin aims to motivate proper behaviour through rewarding interactions and to increase waste collection efficiency. To align with Amsterdam's identity and raise awareness, the appearance will be created in collaboration with local artists.

The Robot Container focuses on providing waste disposal options at will in the city centre, optimising waste management efficiency and reducing littering behaviour, as the current policy allows residents to place waste outside twice a week. The concept reduces the physical burden on employees by eliminating the need to collect waste from the street and minimises the need for heavy waste trucks in the centre.

To assess the concepts' value and feasibility in contributing to a cleaner Amsterdam, stakeholders from the municipality of Amsterdam, department Schoon and AMS Institute evaluated them. Both received positive feedback, with the Robot Container being identified as the most promising solution for achieving a cleaner Amsterdam. However, challenges such as vandalism need to be addressed before implementation. Nevertheless, stakeholders were enthusiastic and asked about implementation activities. A roadmap outlining these activities was developed and evaluated by the AMS expert. However, further research is needed to develop and implement the robots to achieve a cleaner Amsterdam.

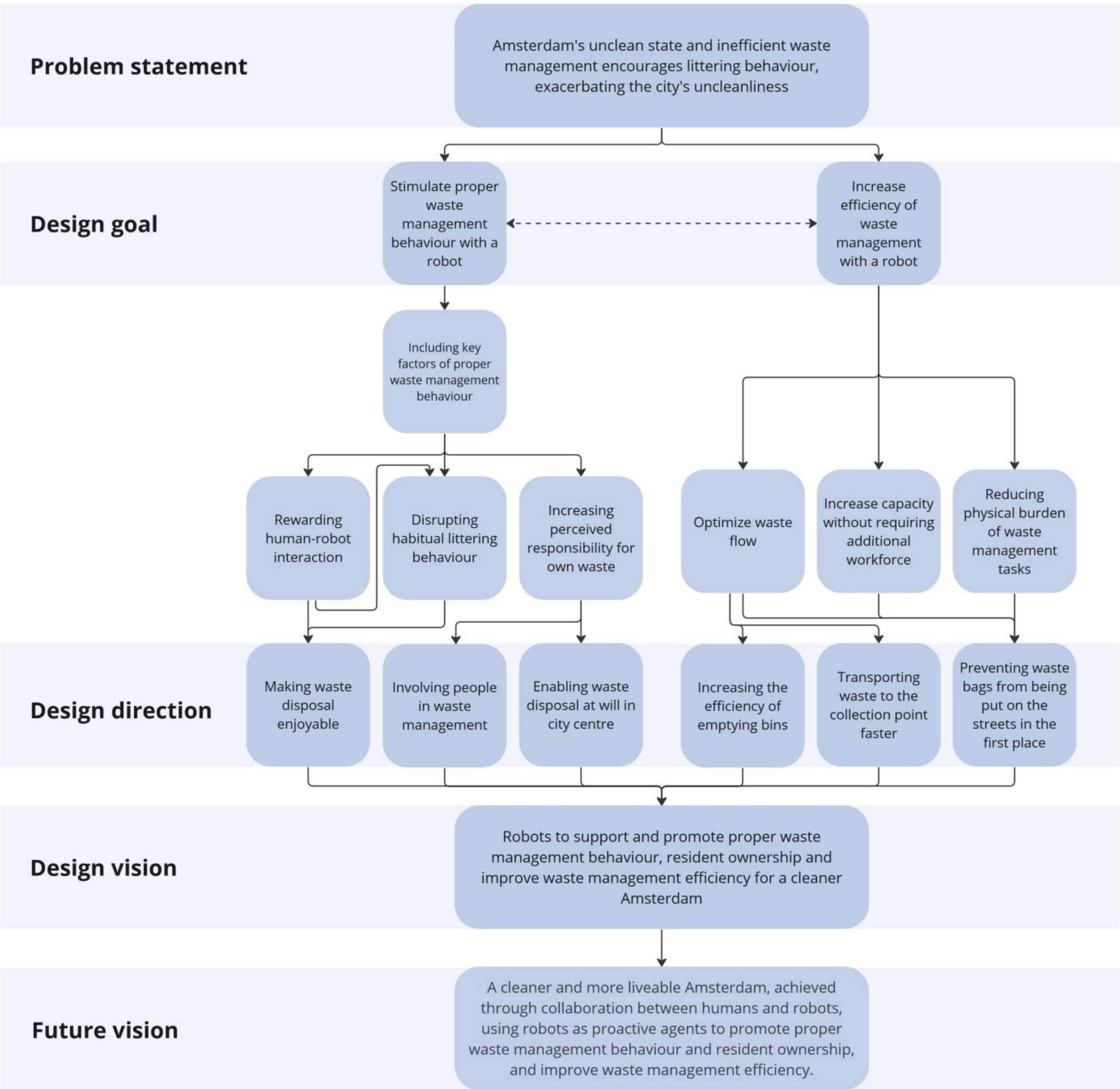


Figure A. This visual provides an overview of the problem statement, design goals, design directions, design vision and future vision to further guide the development of robotic solutions in this thesis that can contribute to a cleaner Amsterdam. The relationship between waste management behaviour and waste management efficiency is shown with a dotted arrow. For example, increased waste management efficiency leads to a cleaner environment, which stimulates correct waste management behaviour, and correct behaviour leads to increased efficiency by reducing the amount of waste to be cleaned up.

1

Introduction

1 Introduction

The city of Amsterdam faces the challenge of maintaining a clean public environment for its residents and visitors: 88.5% of Amsterdam residents experience litter in their neighbourhoods, with 30.4% perceiving it as a significant nuisance (CBS, 2020), impacting their sense of safety and well-being, among other factors. (de Wilde & Huijzer, 2021)

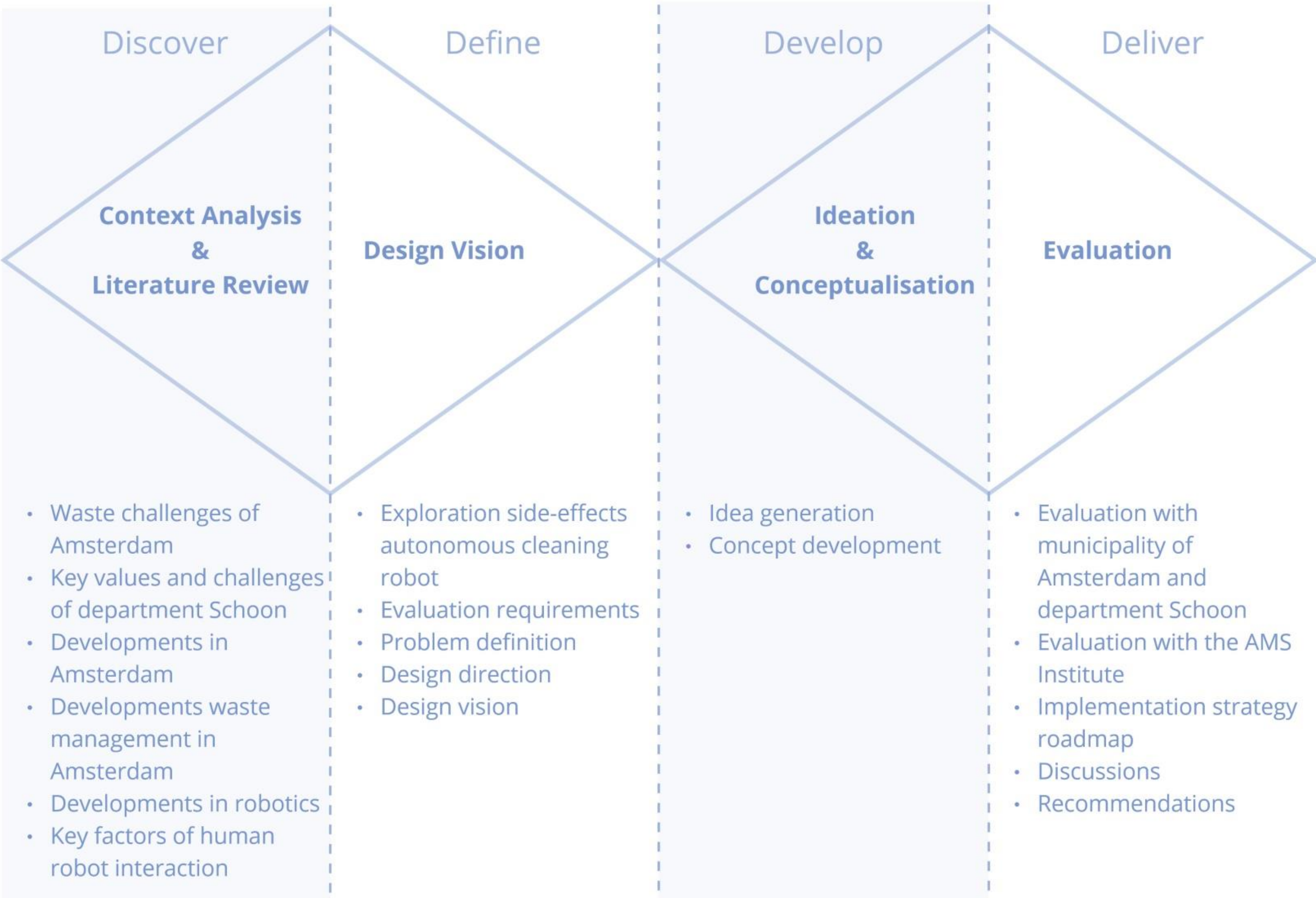
As the current cleaning targets are difficult to achieve with the current resources available, and as the municipality wants to provide the best possible urban environment for its residents, it is exploring alternative solutions such as a robot that can clean the city to help achieve the cleaning targets. However, the fixed function of the robot in the initial request may overlook more effective robotic solutions to address the challenges. To address this issue and explore a wider range of possible solutions, the focus of this research has been redefined to not pre-determine the function of the robot.

Furthermore, as the development and implementation of a robot will take some time, and many developments are likely to take place in Amsterdam in the coming years, the context in which the robot will function is likely to be somewhat different from the current one. In order for a robot to function properly in this future context and make a long-term contribution, it is necessary to understand which developments are relevant and how they will change the context. In order to effectively analyse the future context of Amsterdam within the timeframe of this thesis, it is essential to narrow the scope by specifying a time frame. This allows for a focused examination of the projected future conditions in Amsterdam and facilitates the understanding of relevant developments.

Therefore, in order to ensure a comprehensive evaluation of the changing context, a period of ten years is chosen as the hypothetical deployment timeframe for the robot discussed in this thesis, taking into account the considerable time that is likely to be required for extensive development, testing and refinement of the robot's design. This long term vision is incorporated into the research question of this thesis, which aims to provide an initial exploration of: *"How can robots contribute to a more liveable and cleaner Amsterdam in the long term?"*

This research will be conducted together with the Expressive Intelligence Lab of Delft Design Labs of TU delft and the Institute Advanced Metropolitan Solutions (AMS Institute). The AMS Institute aspires to create sustainable solutions for the challenges cities face and they want to connect science and societal challenges to solve these together.

Given the complexity and potentially unclear frameworks in the context examined in this thesis, it is necessary to adopt an iterative approach that accounts for these uncertainties and effectively addresses the complexity. The Double Diamond Model is used to address these challenges as it provides an iterative framework characterised by divergent and convergent phases that encourage exploration and experimentation. This is crucial in this initial exploration of how a robot can contribute to a cleaner Amsterdam, and in developing a suitable design solution that is adapted to the diverse needs within the context. In addition, the use of the Double Diamond helps to structure this report. The model includes four distinct phases, namely Discovery, Definition, Development and Delivery. (Design Council, 2019) Each phase involves specific



activities, which are shown in Figure 1 and described in more detail below.

Figure 1. To address the proposed research question, a structured approach based on the Double Diamond model was adopted, consisting of four distinct phases with a number of specific steps taken in this project.

Discover

Amsterdam is currently facing significant challenges in maintaining a clean environment. In order to gain a comprehensive understanding of the underlying problems and contextual factors contributing to this issue, a detailed analysis of various layers of the context is necessary. This analysis has revealed the presence of several key stakeholder relationships, as depicted in Figure 2, including People-Waste, People-Robot, and Robot-Waste Relationship.

After conducting a comprehensive analysis of these relationships during the course of this project, it has become evident that the fundamental relationship between people and waste is central to understanding the root causes of uncleanliness in Amsterdam, as well as determining the long-term effectiveness of deploying robotic interventions to promote a cleaner city. Therefore, Chapter 2 examines this critical People-Waste relationship in detail, and provides a framework that takes into account the key factors that influence individuals' waste management behaviour. One such example of an influential factor is the perceived responsibility for one's waste. This framework is applied throughout this thesis to guide the research and analysis.

In order to develop a robotic solution that can effectively address the waste management challenges in Amsterdam, it is essential to gain a comprehensive understanding of the context and underlying problems. Therefore, Chapter 3 focuses on examining waste-related problems in Amsterdam and identifies three main issues: waste bags on the street, waste next to containers and litter in the environment. The chapter employs the behavioural framework outlined in Chapter 2 to investigate the behavioural aspects of these problems and explore the People-Waste Relationships in Amsterdam. This analysis is based on observations and interviews with employees of the city's cleaning department, the department Schoon. In addition, to ensure job satisfaction and to gain insight into their needs when implementing a robot, the chapter examines the core values of the employees of department Schoon. Six key values are identified, including the appreciation of freedom and variety in their work. The chapter also highlights the main challenges encountered by the department, such as labour shortages and reduced efficiency.

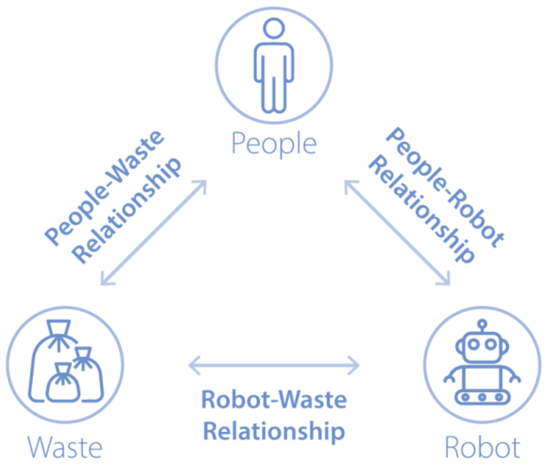


Figure 2. A visual representation of the interdependent relationships among the key stakeholders, emphasising their mutual influence: people, robots, and waste.

To ensure that the robotic solution designed for Amsterdam's waste management challenges remains relevant and continues to meet Amsterdam's needs in the future, it is essential to anticipate contextual developments. To this end, Chapter 3 will outline a review of municipal publications and relevant literature to obtain a better understanding of the urban environment in Amsterdam, and its future vision over the next decade. The objective is to identify potential opportunities, needs, and insights that can inform the subsequent phases of designing the robot and its associated tasks. One of the identified needs is the need for more efficient waste management in Amsterdam due to the growth of the city and the resulting increase in waste.

Furthermore, to provide further insights and opportunities that can be used in subsequent phases to design the robot and its tasks, the technical possibilities of a robot will be explored in Chapter 4, including a review of advancements in robotic capacities. A key finding of this review is the expected growth of robots' capabilities in the coming years, which could significantly improve their task performance. However, it should be noted that achieving full autonomy is still challenging. In addition, since the robot is expected to interact with humans, including employees of department Schoon and people in the urban environment, it is imperative to consider how these interactions can be shaped for optimal outcomes. Consequently, Chapter 4 will also explore the key factors that can contribute to a positive human-robot interaction (HRI), such as the perceived user friendliness and usefulness.

Chapters 3 and 4 will conclude with a set of requirements indicating how the robot can effectively contribute to a cleaner Amsterdam. These requirements will take into account various factors, including the specific needs of Amsterdam and department Schoon, the on-going developments within the city, the key elements that determine a successful HRI, and developments in robot capabilities.

Define

In order to be able to generate ideas for a robotic solution that can effectively address Amsterdam's waste management challenges while aligning with the city's needs and requirements, the defnition phase involves transforming the insights and knowledge obtained during the preceding research phase into a coherent design vision, which will be detailed in Chapter 5. To establish the design vision, an examination of the unintended consequences of the original request made by the municipality of Amsterdam for a cleaning robot is conducted. Given that the Robot-Waste Relationship in Figure 2, which represents the robot's task, indirectly affects the People-Waste Relationship due to the interdependence of these relationships, this assessment uses the behavioural framework outlined in Chapter 2 to examine the effect of the robot's task on the relationship people have with waste. This exploration showed that an autonomous cleaning robot sweeping the streets would have a negative impact on the relationship between people and waste. This necessitates the addition of additional requirements, such as involving people in the waste management process rather than tasking the robot with the responsibility of cleaning, to complement the previously identified requirements. Following this exploration, all requirements are prioritised to form the basis of the design vision. The future vision includes that a cleaner and more liveable Amsterdam will be achieved through human-robot collaboration, using robots as proactive agents to promote proper waste management behaviour and resident ownership, and to improve waste management efficiency.

Develop

In order to effectively communicate the design vision to the municipality of Amsterdam and to demonstrate how a robot can contribute to a cleaner Amsterdam, the aim of this phase is to translate the design vision into tangible deliverables. To achieve this goal, the insights and design directions gained in the Define phase were used to generate ideas in Chapter 6. Three ideas were generated, which were evaluated using the prioritised requirements, resulting in the combination of two ideas into one. The resulting two ideas were developed into two different concepts in Chapter 7: the Mobile Robot Bin, a moving bin that aims to motivate proper waste management behaviour through interaction, and the Mobile Robot Container, an autonomous container into which people can throw their waste at will, in order to avoid waste accumulation and stimulation of littering behaviour in the centre, as there is currently a policy of allowing people to throw their waste on the street.

Deliver

In order to ensure that the developed concepts better meet the needs of Amsterdam in order to be able to effectively contribute to a cleaner city, the final Deliver phase focuses on the validation and evaluation of the concepts by various stakeholders in Chapter 8, including representatives from the municipality of Amsterdam and the department of Schoon. In addition, an expert from the AMS Institute was consulted, as the AMS Institute has extensive knowledge and expertise on Amsterdam's future prospects.

The stakeholders were enthusiastic and positive towards both concepts and unanimously chose the Mobile Robot Container as the most promising and feasible concept to contribute to a cleaner Amsterdam. They asked about the necessary steps to develop and deploy the robots. In order to provide stakeholders with an overview of the required activities, an implementation strategy roadmap was developed and presented in Chapter 9. An example of the activities that need to be carried out is extensive research on how to socially and practically embed the robot in Amsterdam. Finally, chapter 10 concludes with a discussion and recommendations for the city of Amsterdam, including how to address vandalism against robots.

2

Waste Management Behavioural Framework

2 Waste Management Behavioural Framework

As introduced earlier, Amsterdam is facing significant challenges in maintaining the cleanliness of the city, and the relationship between individuals and waste plays a crucial role in understanding the underlying problems and determining the long-term effectiveness of implementing a robotic solution for a cleaner urban environment. To achieve a comprehensive understanding of this relationship, a thorough examination is necessary. The dynamic nature of the relationship that individuals have with waste, as outlined by Rath and Swain (2022), and the mutual influence between behaviour and one's thoughts and feelings towards an object (Kroesen et al., 2017; Jhangiani and Tarry, 2022), waste in this context, highlights the potential value of investigating individual behaviour in relation to waste management practices to gain insights into how the relationship between individuals and waste develops and is influenced.

In order to gain a comprehensive understanding of the evolving relationship between people and waste, the waste management behaviour of individuals is analysed by reviewing literature on the factors that influence this behaviour. To facilitate the ease and effectiveness of utilising the influential factors in this project, the key factors that shape waste management behaviour are incorporated into a framework, as shown in Figure 4, which will be utilised throughout this thesis. In light of the scarcity of existing frameworks on littering behaviour, this thesis adopts the waste management behavioural framework developed by Lyndhurst (2012) on behalf of Zero Waste Scotland and extends it with key factors from various other sources.

The framework of Lyndhurst (2012) identifies four primary clusters of influencing factors on littering behaviour: Personal, Social, Material, and Habitual factors, see Figure 3. Personal factors refer to individual characteristics and influences, while social factors refer to the broader social context that shapes our mindset and actions. Habitual factors represent patterns of behaviour that are ingrained in the subconscious of an individual, while material factors represent the setting in which behaviours are performed. A more detailed explanation of these key factors can be found in Appendix A.

It is worth noting that the key factors within these four clusters can either motivate proper waste disposal behaviour or littering behaviour. Additionally, certain factors can reduce the likelihood of the desired behaviour and act as a barrier to proper waste disposal behaviour. Therefore, these factors can be categorised into three groups: motivators for littering behaviour, motivators for proper waste disposal behaviour, and barriers to proper waste disposal behaviour. (Lyndhurst, 2012) This classification has been illustrated in Figure 3, and will serve as a fundamental framework that will be utilised throughout this thesis as a tool to identify and address the waste challenges in Amsterdam and develop effective robotic solutions to maintain a cleaner urban environment.

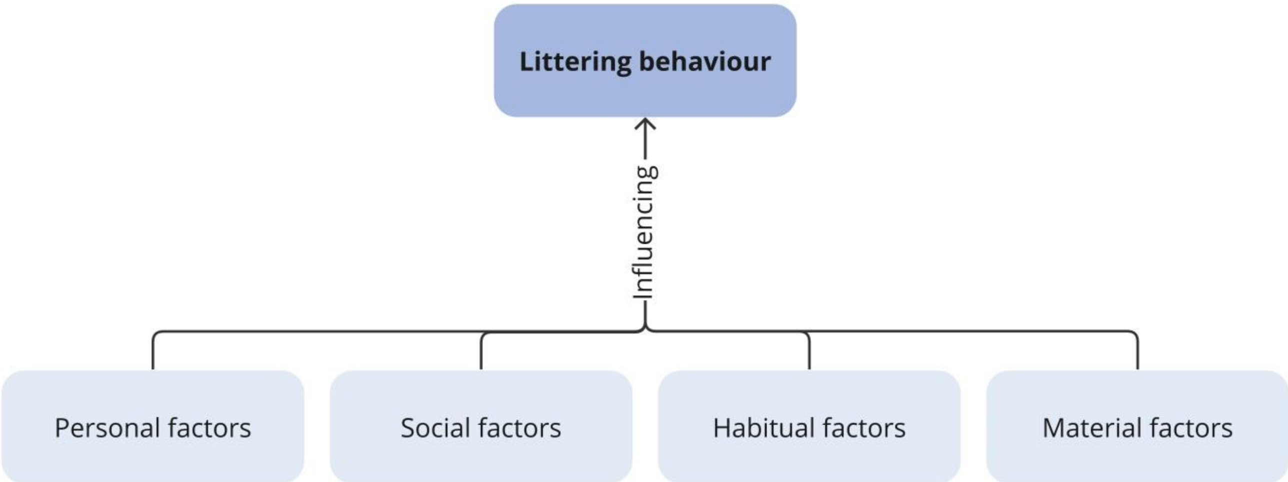


Figure 3. Littering behaviour is influenced by of a broad spectrum of factors, which can be categorised into four clusters, based on Lyndhurst (2012).

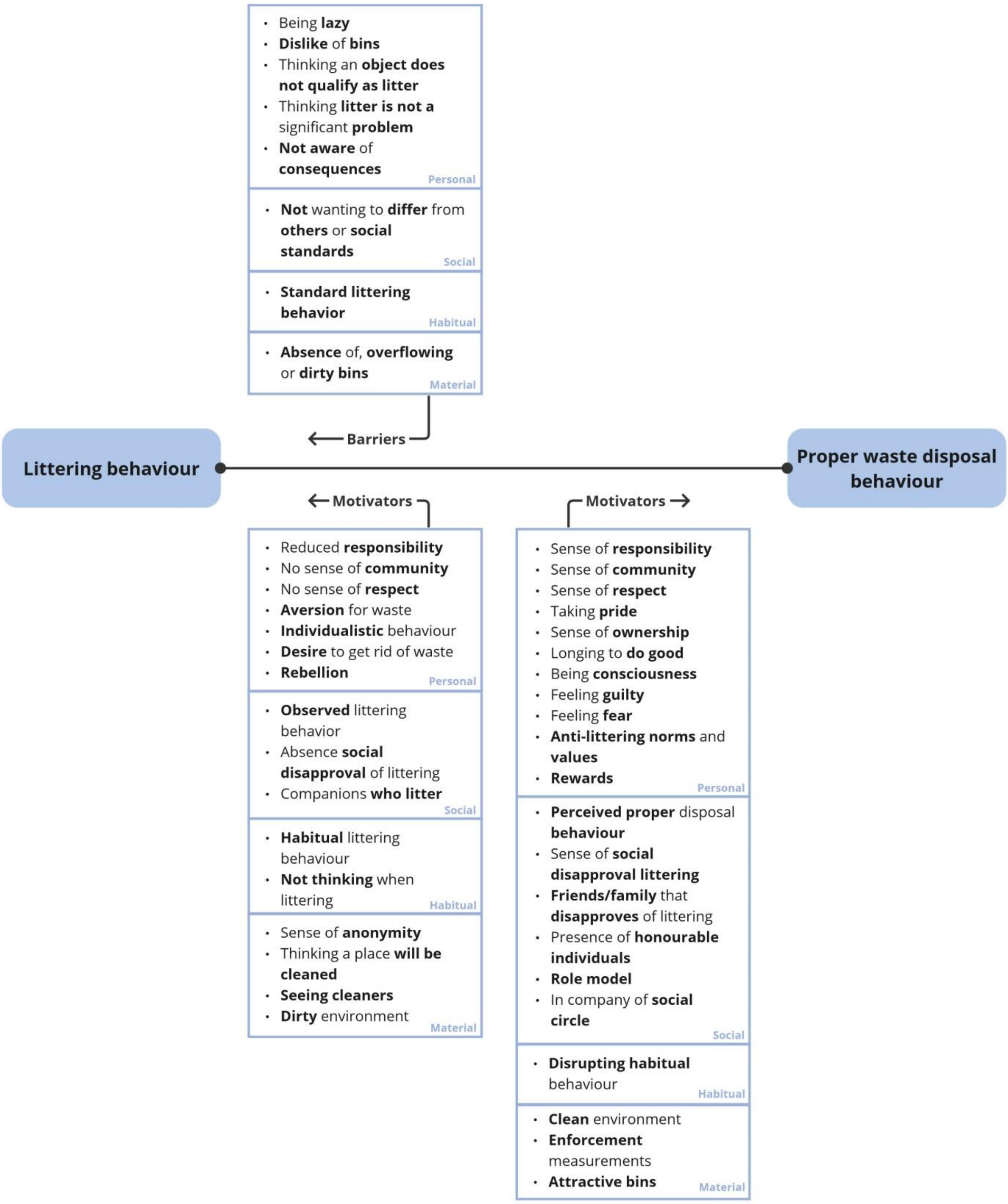


Figure 4. This framework provides a comprehensive overview of the many factors that influence waste management behaviour, highlighting the complex nature of this behaviour and the influence of the various factors that ultimately encourage either littering or proper waste management behaviour. This framework is based on the work of Lyndhurst (2012), which includes four main clusters (e.g. personal factors) and three categorisations (e.g. motivators), as well as various factors influencing waste management behaviour. In addition to the Lyndhurst framework, additional factors from various other sources are added. (Cialdini et al, 1990; Huffman et al, 1995; Williams et al, 1997; Campbell, 2007; Barr, 2007; de Kort et al, 2008; Lewis et al, 2009; Victorian Litter Action Alliance, 2009; Alice Ferguson Foundation, 2011; Het Centrum voor Criminaliteitspreventie en Veiligheid, 2016; Texas Disposal Systems, 2023; Ministerie van Infrastructuur en Waterstaat, n.d.-a)

3
Context Analysis Amsterdam

3 Context Analysis Amsterdam

Amsterdam is currently facing challenges in maintaining the cleanliness of the city, which has resulted in significant inconvenience for its residents. To develop appropriate solutions that can have a long-term impact on improving the liveability and cleanliness of the city, it is crucial to gain a comprehensive understanding of the context in which the robot will operate. The methodology used for the contextual analysis of Amsterdam is outlined in Chapter 3.1. To gain a thorough understanding of the context in which the robot will operate, a detailed analysis of the existing waste-related challenges in Amsterdam is necessary to understand the nature of the challenges and to identify the areas where a robot could have the greatest impact, see Chapter 3.2.

The employees of the department Schoon, who are responsible for cleaning the city, are an integral part of the context and are therefore important stakeholders when implementing a robotic solution. Therefore, an analysis of their job satisfaction and values is necessary to ensure that the implementation of a robotic solution aligns with their needs and values. Chapter 3.3 will identify the factors contributing to their job satisfaction and examine the challenges faced by the employees and the department to identify areas where a robotic solution can provide value.

Since developing a robotic solution can be a time-consuming process, and the context in which the robot will operate is likely to change by the time it is ready for implementation, it is critical to analyse the developments in Amsterdam. This analysis will help to anticipate the future context and enable the design of a more suitable robotic solution that meets the future needs of Amsterdam, as discussed in Chapter 3.4.

Moreover, to ensure that the robotic solution aligns with the future waste management practices of Amsterdam, an analysis of the developments in this field in Amsterdam will be conducted. This will provide insights into the way waste management in Amsterdam will look like in the coming years, ad detailed in Chapter 3.5.

Overall, the context analysis in this chapter aims to provide a comprehensive understanding of the current and future context of Amsterdam, as well as the needs and values of the stakeholders involved. This understanding is essential for the design of a successful and long-term contributing robotic solution that can address the city's waste problems and improve the cleanliness and therefore the liveability of Amsterdam. Chapter 3.6 provides a conclusion to this chapter.

3.1 Method

Given the complex challenges that Amsterdam faces in maintaining a clean city, and the daily exposure to these challenges of the employees of department Schoon, it was considered that the exploration of valuable insights into Amsterdam's waste management could be facilitated not only through online resources, but also through consultation with the experienced employees of department Schoon. Therefore, in order to gain a deeper understanding of this context, it was considered essential to immerse myself in the city and accompany the employees of the department Schoon.

To facilitate this immersion, I engaged on four occasions in full-day walk-along sessions with employees from the Department Schoon of Amsterdam, see Figure 5, in the company of another graduate student, Enzo Steehouwer, who was doing his master's thesis on the key work values of the employees of Department Schoon. As I was in the preliminary stage, an attempt was made to gain a more in-depth understanding of the context. To achieve this, an unstructured interview method with specific predetermined topics was used, as this method allows for a comprehensive exploration of the interviewees' beliefs, experiences and thoughts, and promotes a more natural and open conversation, making participants feel more at ease. (Zhang & Wildemuth, 2009) The direction of the interviews was guided by the responses provided, focussing on predetermined areas such as their work preferences, dislikes, essential aspects of their work, work-related challenges, and prospects for internal and external improvements. In addition to the unstructured interview, the team's work processes and challenges encountered were observed during these sessions. However, due to the limitations of participating in the sweeping activities and the fast pace of the walk-along sessions, it was not always possible to take photographs.

After conducting the interviews and observations, the obtained insights were discussed with Steehouwer, to develop a more comprehensive and nuanced understanding of the context and the key values underlying the department's workforce, drawing on our respective perspectives and expertise. Moreover, to enhance the validity and relevance of the conclusions, the findings were subjected to an additional layer of research and analysis by Steehouwer (2022) in his master's thesis.

Figure 5. Two pictures of me immersing myself in the context of this thesis: one with the employees of the department Schoon and one where I am cleaning the streets.

Furthermore, to gain a more extensive understanding of the context, a range of information sources were consulted. These included conducting discussions with Ruben van Thal, the group leader of department Schoon in the centre of Amsterdam, concerning the most common waste management issues in the city. Additionally, relevant literature on general urban developments, developments in Amsterdam, and waste management developments in Amsterdam was reviewed, along with published municipal documents and news articles related to Amsterdam, to gain further insights.

In order to determine the areas in which the robot can effectively address Amsterdam's waste problems, a systematic approach was adopted, starting with the identification of the prevalent waste problems through a comprehensive range of information sources, as explained earlier. This was followed by an assessment of the extent to which Amsterdam's waste management practices contribute to these problems. During the analysis it became evident that human behaviour plays a significant role, sometimes compounded by other factors. Consequently, these elements were included in the analysis and the key factors outlined in the waste management behaviour framework presented in Chapter 2 were used to understand the underlying causes of this human behaviour. Finally, the interrelationships between these components were explored, with the ultimate goal of identifying the specific areas where the robot can make the most significant contribution to promoting a cleaner Amsterdam. A visual representation of the methodology used to identify the areas of greatest added value for the robot is shown in Figure 6.

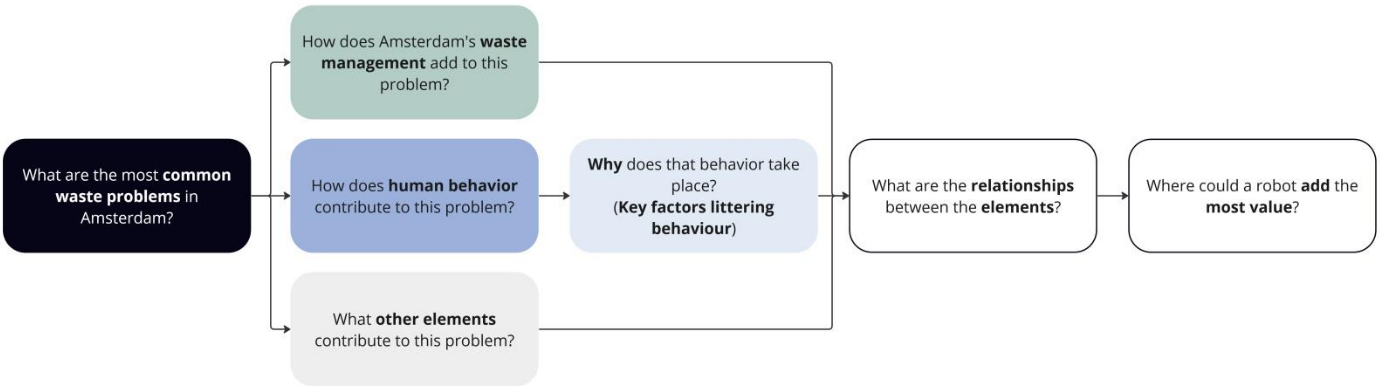


Figure 6. This illustration represents a flow diagram outlining the employed methodology for identifying areas wherein the robot presented in this thesis can effectively contribute to enhancing the cleanliness of Amsterdam. The colour coding corresponds to that of Figure 15.

In order to identify relevant developments and trends that will influence Amsterdam's urban environment over the next decade, the DEPEST methodology was used. This framework is commonly used to understand the external environmental factors that have a significant influence. (van Boeijen et al., 2013) The methodology includes six categories, namely Demographic, Economic, Socio-cultural, Technological, Ecological and Political, in which relevant developments were examined. The search was limited to developments that would have a significant impact on urban life in Amsterdam to ensure context specificity.

3.2 Waste Challenges of Amsterdam

The management of public space in Amsterdam is carried out using a single urban standardization, monitoring and inspection system; the CROW measurement system. This system defines several measurable levels of cleanliness. Pursuing the cleanest objective would be, however, too expensive and would cause too much street congestion and inconvenience. Since this is not desirable, the cleaning objective pursued by Amsterdam is 'verzorgd' (well-kept), which corresponds to objective B of the CROW system. (CROW, 2018) Nonetheless, as evidenced in Figure 7, the majority of Amsterdam's regions fail to meet objective B, with the central district registering the lowest score and the highest levels of pollution according to the CROW measurement system. In addition, research conducted by the municipality of Amsterdam highlights that their residents experience significant nuisance from these polluted surroundings. (Gemeente Amsterdam, 2016; Onderzoek en Statistiek, 2023)

In response to the municipality's request to explore the feasibility of introducing a robot to aid in achieving Amsterdam's cleaning objectives, an in-depth analysis of the city's prevalent waste issues will be conducted. This analysis aims to identify the root causes of uncleanliness and waste problems and determine areas where a robotic intervention could effectively enhance the cleanliness and liveability of Amsterdam.

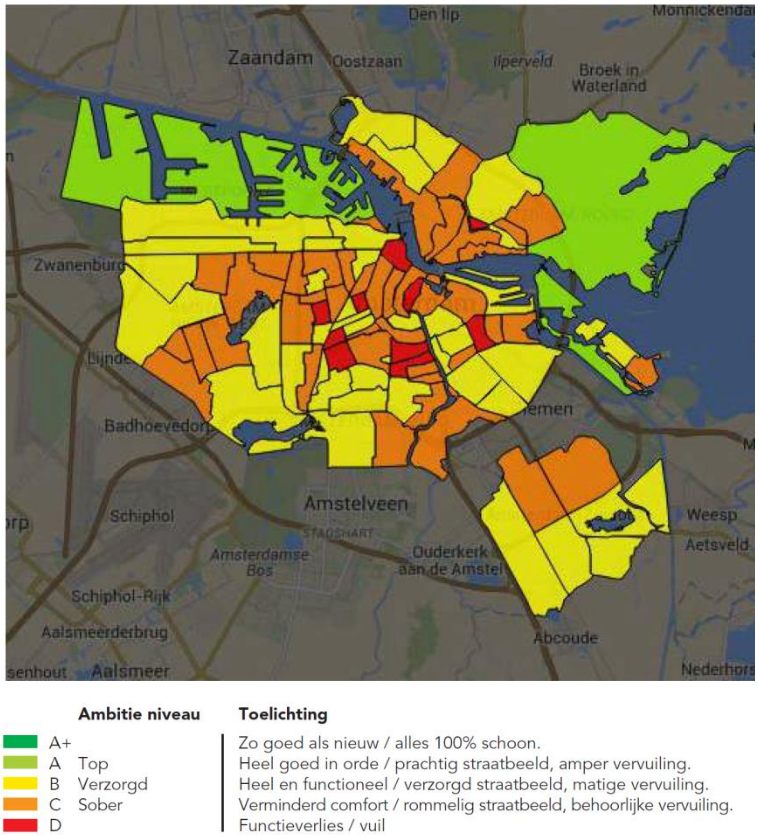


Figure 7. The map of Amsterdam based on CROW measurements shows that the current cleaning targets are not being met, with the city centre being the most affected by the accumulation of waste. Image taken from Gemeente Amsterdam (2016).

The identification of the most prevalent waste problems was achieved through the analysis of observations, interviews with employees of department Schoon, discussions with Ruben van Thal, and news articles related to waste problems in Amsterdam. As a result of this comprehensive analysis, three primary waste challenges in Amsterdam were identified, each of which presents complex challenges with different origins. The subsequent section will outline and provide detailed explanations of these frequently occurring waste problems and their underlying causes.

During the analysis of the waste problems, it became evident that human behaviour plays a significant role in contributing to these issues. This notion was reinforced during a discussion with Ruben van Thal, the groupleader of department Schoon, who emphasised the importance of acknowledging this factor. He stated that, "The biggest polluters are humans themselves, the public space would basically look beautiful if everyone followed the rules, unfortunately this is not the case." To obtain a more comprehensive understanding of the underlying causes of these waste problems, an in-depth examination of the human behaviour related to improper disposal of waste in public spaces, known as littering behaviour (Cambridge Dictionairy, n.d.), will be conducted. To provide a deeper understanding which key factors are of influence in the various waste problems, the framework of Chapter 2 will be utilised throughout this analysis.

Trash Bags on the Streets

The current policy for waste management in the central district and some other areas of Amsterdam permits residents to dispose of household waste on the street one or two times a week for collection by the department Schoon. Residents are bound by municipal regulations and cannot decide for themselves when to dispose of their waste. (Van Der Knaap, 2021) This low-frequency collection schedule often results in a build-up of waste on the streets, as residents tend to hold onto their waste until the designated days, leading to piles of waste that take up significant space and detract from the appearance of the city's streets. (AT5, 2019)

This accumulation of waste on the streets creates a visibly unclean environment, see Figure 8, which is a key factor of the waste management behavioural framework that can stimulate littering behaviour among individuals, see Figure 9. (Lyndhurst, 2012; Het Centrum voor Criminaliteitspreventie en Veiligheid, 2016; Texas Disposal Systems, 2023; Ministerie van Infrastructuur en Waterstaat, n.d.-a) This often results in additional waste being improperly disposed of next to the visible waste bags, leading to a significant amount of litter remaining behind even after the bags are collected. The employees of the department Schoon follow a tight schedule and may not have adequate time to remove the litter that is left on the ground next to the bags due to their high workload, which will be discussed in further detail in Chapter 3.3. As a result, litter remains on the streets, which attracts rodents and birds, see Figure 10, which in turn further spread the waste along with the wind, leading to a vicious cycle of litter accumulation. (AT5, 2020a, 2021a)

Figure 8. The presence of waste bags on the street in Amsterdam, often placed outside of scheduled collection times, leads to a dirty environment and encourages littering behaviour.

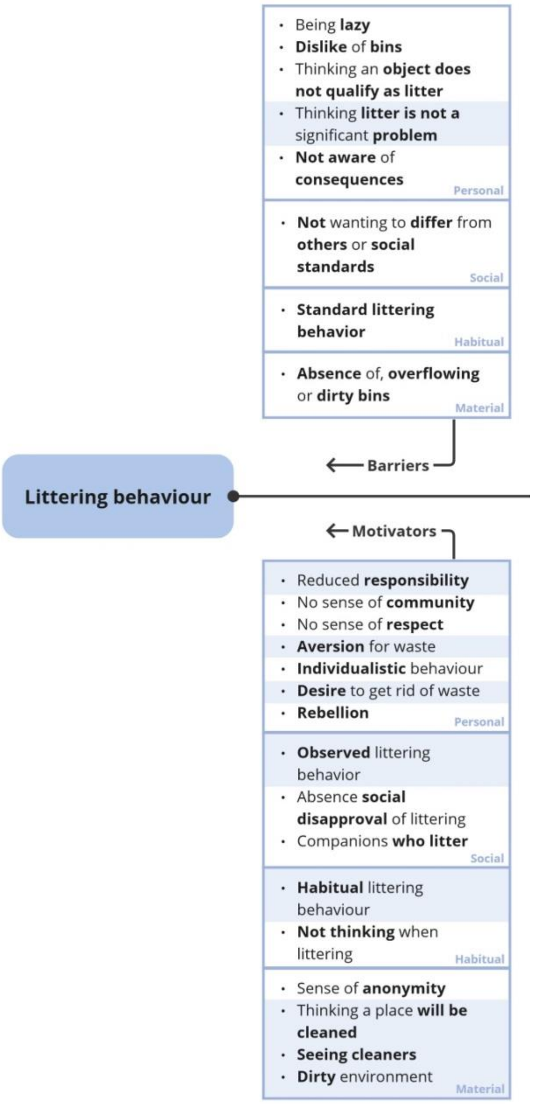


Figure 9. The key factors that are 'triggered' by the practice of placing waste bags on the streets are highlighted, emphasising the significant impact of this policy in the centre on stimulating littering behaviour.

Furthermore, research suggests that the amount of litter present in a particular area and the perceived behaviour of others significantly influence an individual's likelihood of littering, as they may perceive this as permission to engage in the same behaviour, thereby increasing the occurrence of littering. (Lyndhurst, 2012) This is particularly relevant in the context of Amsterdam, where residents observing others placing bags on the street or noticing the presence of bags, may justify their own littering behaviour or give the impression that disposing of an additional item improperly is inconsequential. It should be noted, however, that litter does not necessarily have to be visible, as people may justify their littering behaviour if they know that litter was previously present in a particular place. (Williams et al., 1997) This may explain may explain why people choose to dispose of their waste on the streets outside of scheduled times, such as when they have forgotten the designated times or when they have accumulated too much waste in their homes and wish to dispose of it as soon as possible. During the walk-along sessions, there were numerous instances of incorrectly disposed garbage bags placed on the street outside of scheduled times. On one occasion, a pile of garbage bags several metres high was observed on the street, though unfortunately no photos were taken.

Figure 10. The waste bags on the streets in Amsterdam attract birds, which, along with the wind, contribute to the spread of waste, maintaining a vicious cycle of waste accumulation. Image taken from Gigi (2023).

Moreover, studies have shown that people are more likely to litter when they believe a space is being cleaned (Lyndurst, 2012), as they perceive it as a more acceptable place to dispose of waste. (Lewis et al., 2009) This may explain why people occasionally put trash bags on the streets outside designated times, leaving them there for several days with no apparent owner. They may believe that the municipality of Amsterdam will ultimately clean up the mess, which reduces their perceived responsibility for their waste and increases the likelihood of littering behaviour. (Campbell, 2007) Additionally, the visible presence of cleaners in a particular place, and in this case in Amsterdam, can reinforce the sense that a place is being cleaned, thereby reducing the perceived responsibility for one's waste. (Lyndhurst, 2012) This is exemplified by instances where employees have encountered people throwing their waste bags from their balcony onto the ground and requesting the employees to dispose of them. One employee stated, "People sometimes come to me asking if I can take their waste, but I am not obliged to take it. However, if it fits, I sometimes do. My presence and their surplus waste cause them to approach me from time to time."

In addition, the current policy of allowing residents to put their waste on the streets twice a week in the city centre may encourage a bad habit of putting waste on the streets, which can further stimulate littering behaviour. (Lyndhurst, 2012)

Waste Next to Containers

The issue of waste accumulation near containers is a significant problem in Amsterdam, see Figure 11. (Wagemakers, 2021) According to interviews conducted by AT5 with local residents, this problem is largely attributed to the insufficient frequency of garbage collection, which leaves the containers full for extended periods of time. (AT5, 2020b) In addition, the rise in online shopping has led to an increase in cardboard waste, exceeding the container capacity, and causing people to leave cardboard next to the containers, along with other waste. (AT5, 2021b) The sight of full or littered containers can discourage people from properly disposing of their waste, leading to a vicious cycle of litter accumulation that attracts rodents and birds, which, in turn, further contribute to the spread of waste, along with the wind, sustaining a vicious cycle of litter accumulation.

There are multiple contributing key factors of littering behaviour to the issue of litter accumulation near containers, see Figure 12. One such factor is when residents perceive clogged, full or littered containers, they may perceive the waste issue as the municipality's responsibility instead of their own, which can further diminish the sense of responsibility and motivate residents to deposit their waste next to the containers. In addition, a littered environment may create the feeling that littering behaviour is justified. Next to that, residents may believe that someone, in this case the municipality, will eventually clean up the area. Laziness is another key factor, as individuals may be disinclined to seek out alternative containers. (Texas Disposal Systems, 2023) Furthermore, the perceived dirtiness of the object to be discarded is another key factor: the greater the perceived dirtiness, the greater the reluctance to keep the waste and the stronger the desire to dispose of it quickly. (Lyndhurst, 2012) The availability and perception of the bins also play a role in littering behaviour, as people may be less inclined to dispose of their waste properly if the bins are perceived as full or dirty. (Williams et al., 1997; Texas Disposal Systems, 2023) Moreover, witnessing other individuals depositing waste adjacent to a container or perceiving the presence of waste, can potentially rationalise one's own littering behaviour or give rise to the impression that disposing of an additional item in an inappropriate manner is of little consequence. Furthermore, a lack of sense of community in a neighbourhood can also act as a motivator for littering behaviour. (Lyndhurst, 2012)

The waste left next to the containers also presents a logistical challenge for the department Schoon. Before waste trucks can empty the containers, the waste next to the containers must be manually removed, leading to congestion and inefficiency in the waste collection process. (AT5, 2020c)

Figure 11. A visible accumulation of waste near containers can act as a trigger for littering behaviour, increasing the accumulation of waste. Image taken from Wagemakers (2021).

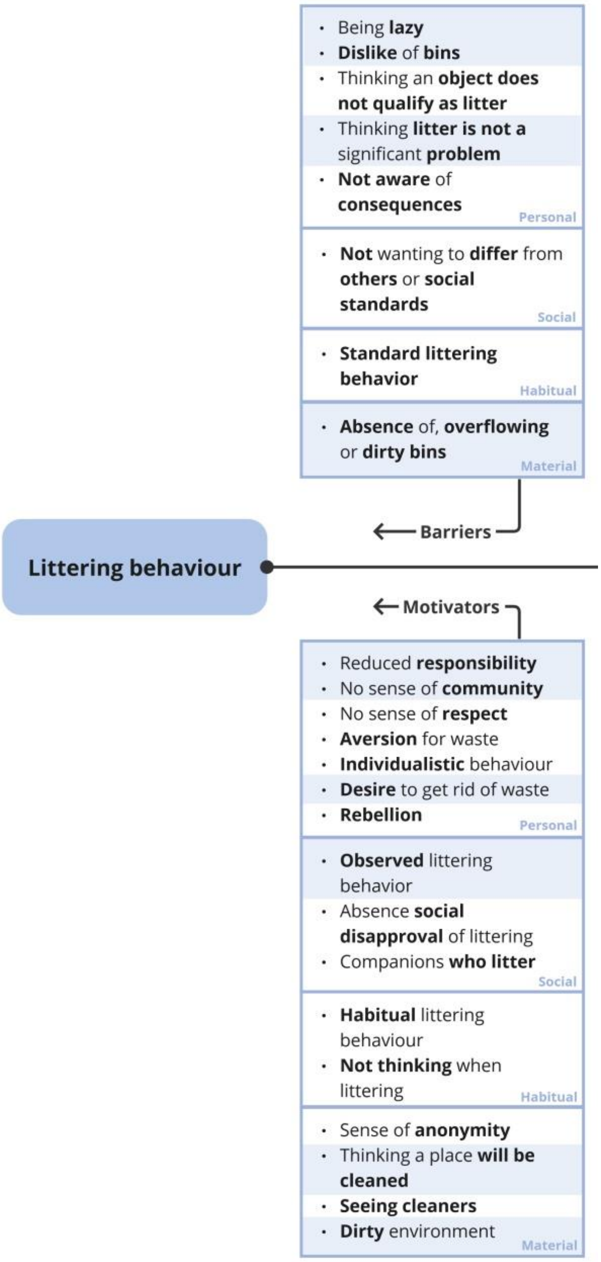


Figure 12. The key influencing factors of littering behaviour that lead to waste being deposited next to containers are highlighted.

Litter

Amsterdam is faced with a significant challenge of litter accumulation on its streets, see Figure 13, with the problem being particularly prominent in the city centre. Most complaints regarding the pollution of the environment are concentrated in this area. (AT5, 2020b) Cigarette butts, plastic bottles, cans, single-use plastic such as straws, packaging, and grocery bags are the most commonly littered items. (Queensland Government, 2021; National Geographic Society, 2022; Texas Disposal Systems, 2023) The environmental and societal impact of litter is substantial, with negative effects on our sense of well-being (Broeders et al., 2010), increasing negative behaviours like crime, (Kelling et al., 1982) and costing a considerable amount of money to clean up (Rowe, 2019), with an estimated annual cost of 300 million euros in the Netherlands (Milieu Centraal, n.d.).

Figure 13. Litter in the environment may incentivise individuals to engage in inappropriate waste disposal behaviour. Image taken from Redactie Amsterdam (2021).

The underlying causes of litter in Amsterdam are complex and involve a diverse range of key factors that contribute to individual littering behaviour. As the framework presented earlier is based on littering behaviour, all the key factors illustrated in Figure 14 come into play when examining the reasons why waste is deposited inappropriately. Research indicates that people are more likely to engage in littering behaviour when they observe litter in their immediate surroundings or are aware of a location's previous lack of cleanliness. (Het Centrum voor Criminaliteitspreventie en Veiligheid, 2016; Texas Disposal Systems, 2023; Ministerie van Infrastructuur en Waterstaat, n.d.-a) Moreover, an individual's sense of personal responsibility for their waste and the environment can be influenced by their level of connection to a particular place. (Campbell, 2007) In the case of Amsterdam, individuals who do not feel a sense of responsibility towards the city may be more likely to litter. The presence of cleaners or the feeling a place will be cleaned up can also reduce an individual's sense of responsibility for their waste. (Lyndhurst, 2012) Additionally, the feeling of anonymity in a large city like Amsterdam can contribute to and enhance littering behaviour. (Ministerie van Infrastructuur en Waterstaat, n.d.-a)

Another important key factor is the level of awareness people have about waste, such as understanding the consequences of littering or having a clear perception of what qualifies as litter. A lack of knowledge about the impact of littering can lead to the perception that littering is not a significant issue, which may hinder desired waste disposal behaviour. For instance, cigarette butts or small biodegradable items are often not recognised as litter, leading people to dispose of them improperly under the mistaken belief that the consequences are minimal. (Lyndhurst, 2012) Furthermore, encountering dirty or overflowing bins or having insufficient access to trash containers can contribute to the motivation of littering behaviour, as people can feel justified to litter. (Williams et al., 1997) The key factor laziness can enhance this, as individuals may be disinclined to seek out alternative containers. (Texas Disposal Systems, 2023) Additionally, the perceived level of dirtiness of an object to be discarded can influence an individual's willingness to retain waste, thereby strengthening their desire to dispose of it quickly. (Lyndhurst, 2012)

Social influence can also play a role in littering behaviour, as people tend to adopt the behaviour of those around them to avoid social rejection. One's upbringing and the examples one has received of how others deal with waste are also factors of influence. Additionally, bad habits can contribute to littering behaviour, and an individual's personal norms and values concerning waste disposal are critical factors that can either motivate or discourage littering behaviour. (De Kort et al., 2008, Lyndhurst, 2012)

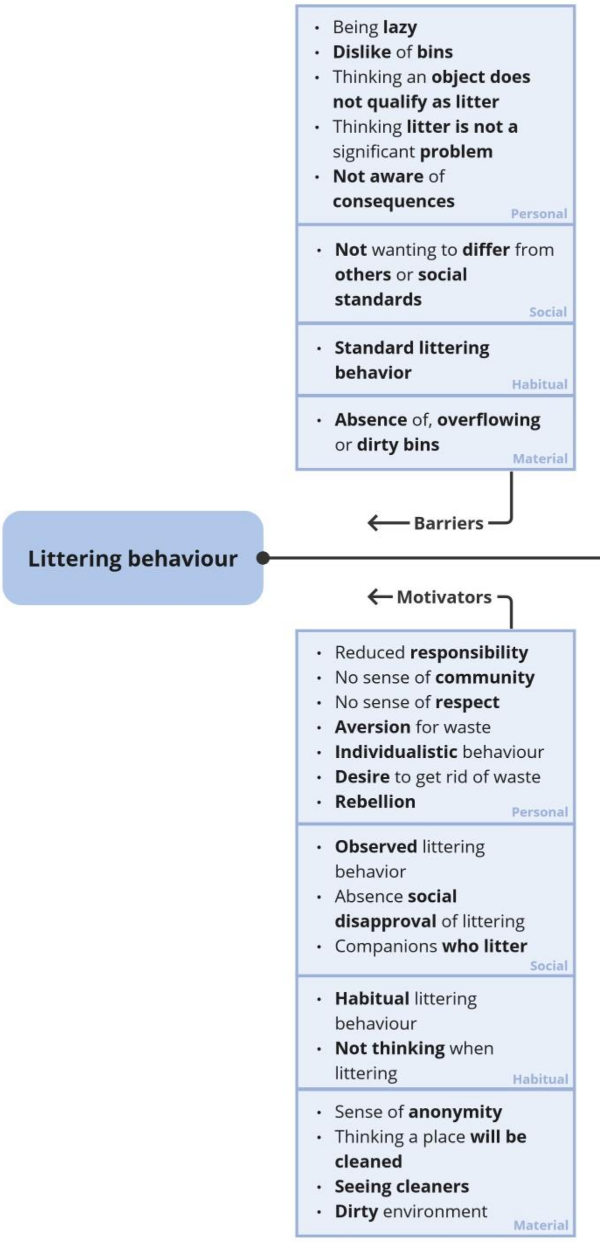


Figure 14. As the framework presented in this visual includes the key factors influencing littering behaviour, all factors are highlighted when examining the reasons behind inappropriate waste disposal.

In addition, overflowing bins, due to high usage or insufficiently frequent emptying, can lead to people depositing their waste next to the bins, see Figure 13. Furthermore, broken or damaged trash cans, often resulting from individuals attempting to retrieve items with deposits, can exacerbate the problem. Hence, the problem of littering in Amsterdam can be attributed, in part, to inefficient waste management infrastructure, where overflowing, full, or damaged waste bins can lead to improper waste disposal practices. However, it is important to note that studies have shown that placing more trash cans or emptying bins more frequently has limited effectiveness on reducing littering behaviour. (Campbell, 2007) This is because a significant proportion of littering occurs within five metres of a trash can, and a significant number of people tend to throw their waste on the ground instead of looking for a bin. (Williams, et al., 1997; Victorian Litter Action Alliance, 2014)

Conclusion Waste Problems

Currently, the cleaning targets in Amsterdam are not being achieved, leading to significant inconvenience for residents. A comprehensive analysis has identified three primary waste issues in Amsterdam, each presenting complex challenges with distinct origins. Figure 15 provides an overview of the analysis of these waste problems. To differentiate between waste problems, waste management, littering behaviour, key factors influencing littering behaviour, and other relevant elements not belonging to the aforementioned categories, a categorization system is established using distinct colour codes.

The primary cause of the first waste problem, which is the presence of waste bags on the streets, can be mainly attributed to waste management policies that allow individuals to dispose of waste bags in public areas, leading to an accumulation of litter. The right-hand side of Figure 15 shows a self-reinforcing cycle in which the accumulation of waste stimulates littering behaviour, which in turn leads to even more accumulation of waste. A robot could potentially be of value in mitigating this issue by preventing waste bags from being put on the streets in the first place, thereby reducing the accumulation of waste and associated problems. Such a solution could potentially foster a better waste relationship between residents and their surroundings.

The second issue, which is the accumulation of waste next to containers, stems primarily from inefficient waste management practices. Due to full or clogged containers, residents are unable to dispose of their trash. This stimulates people to display littering behaviour, leading to dirty or littered containers and contributing to the accumulation of waste around the containers in Amsterdam. The accumulation of waste further presents a logistical challenge for the department Schoon, leading to traffic congestion and inefficiency in the waste collection process. To address these challenges, the integration of a robotic solution into the city's waste management system could be of value when it improves the efficiency and effectiveness of waste collection processes. This solution could also potentially reduce littering behaviour and waste accumulation around containers, as it would enable residents to dispose of their trash whenever they want.

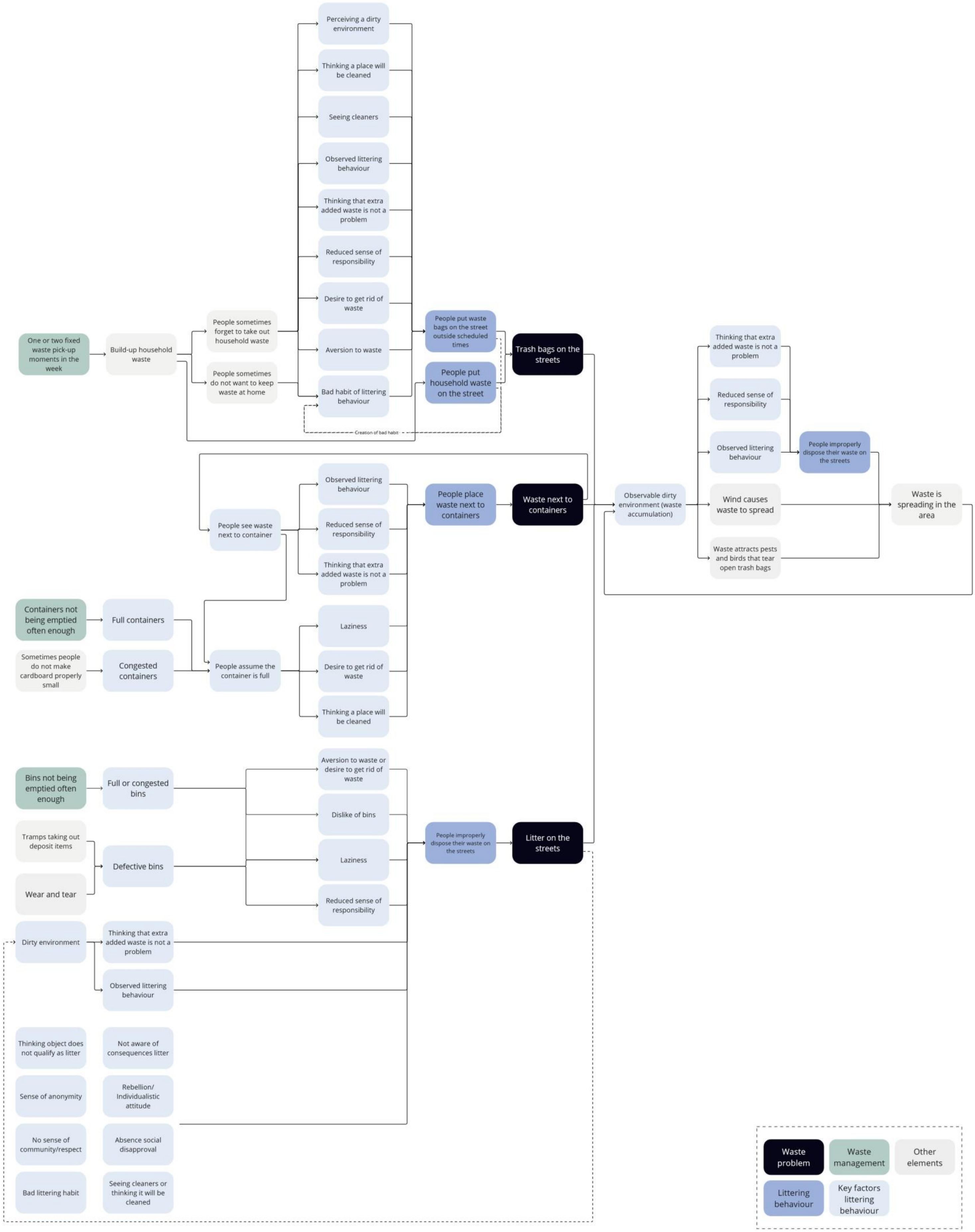


Figure 15. The analysis of the three primary waste problems reveals their complexity and shows that the first two problems are mainly due to inefficient waste management policies, while the third problem, littering, is mainly due to human behaviour. It also shows that the three waste problems form a self-reinforcing cycle in which the accumulation of waste stimulates the tendency to litter, which in turn exacerbates the accumulation of waste.

In contrast, the third issue of litter on the streets is primarily driven by complex human littering behaviour, particularly in the city centre, which is heavily affected by pollution. The high number of tourists in this area also presents a challenge in addressing this behaviour, given that behavioural change is a time-consuming process. Nevertheless, robots could be of value when they are able to promote proper waste disposal behaviour, thereby preventing littering. This could lead to a cleaner environment and enhance the overall waste relationship between individuals and their surroundings.

In conclusion, Amsterdam faces several complex waste challenges that lead to significant inconvenience for residents, including the accumulation of waste bags on the streets, waste next to containers, and litter on the streets. While each of these issues has distinct origins, inefficient waste management policies and human littering behaviour are the primary causes. This inefficiency in waste management policies, in turn, has an indirect influence on stimulating littering behaviour, which is also demonstrated in the waste management behavioural framework as the key factor material, e.g. the state of a bin, is directly influenced by the effectiveness of waste management policies, as shown in Figure 16. While it will be challenging for a single robot to address all waste issues, integrating robotic solutions into the city's waste management system could potentially reduce the accumulation of waste and encourage proper waste disposal behaviour. By fostering a better relationship between individuals and their waste, a cleaner and more sustainable city can be achieved.

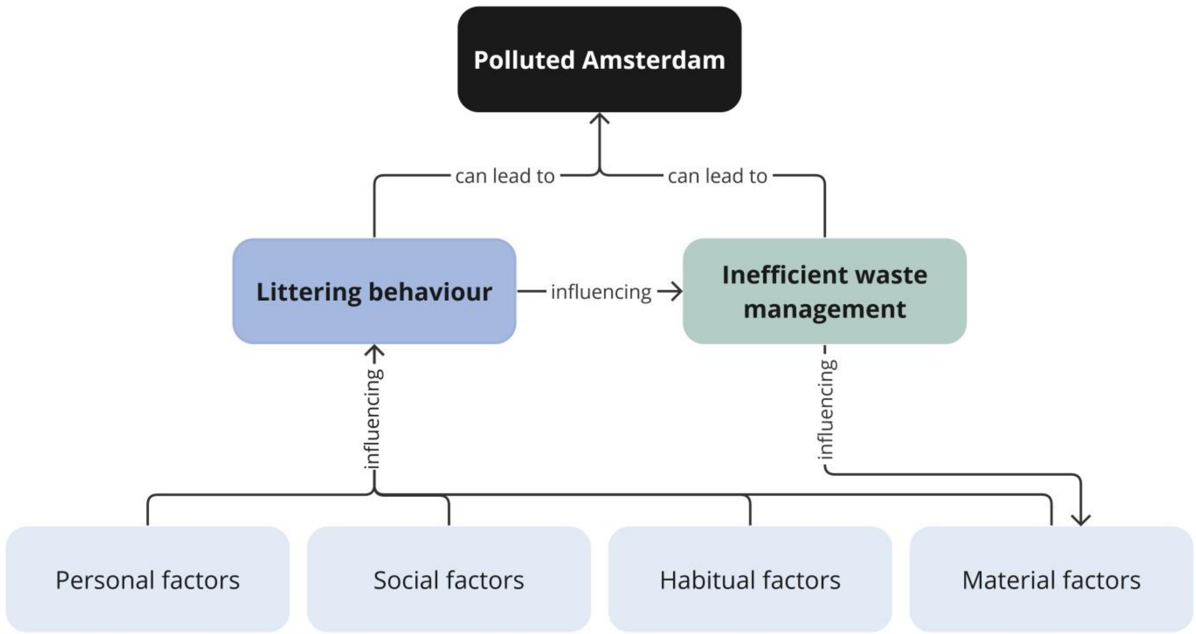


Figure 16. This visual shows the relationship between littering behaviour and inefficient waste management. The material factors, i.e. the state of the waste management infrastructure, such as the condition of the bins, influence littering behaviour, highlighting the influence of inefficient waste management on littering behaviour. Littering behaviour also has an impact on waste management, as the accumulation of waste can reduce efficiency due to longer clean-up times.

3.3 Key Values and Challenges of Department Schoon

As the department Schoon is an integral part of the municipality of Amsterdam and its employees are expected to collaborate or interact with the robot proposed in this thesis when it is implemented, this section will outline the critical values identified during the walk-along sessions. As these values are important for job satisfaction, they can be used in designing the robot's task to ensure that these values are not violated and that job satisfaction is guaranteed. Additionally, this section will elaborate on the observed challenges encountered by the department, as these insights could prove useful in determining how a robot could be of assistance.

Key Values Employees Department Schoon

During the walk-along sessions, it was observed that the interviewed employees generally expressed high levels of job satisfaction with their work and wages. Additionally, many of the employees displayed a strong passion for their city and pride in their work. The latter aspect is interesting given the negative association people typically have with waste workers. (Ashforth et al., 2007) This finding highlights the positive aspects of this type of work, as viewed by the employees themselves, and thereby counters the stigma that is often associated to cleaning and waste management professions. Subsequently, the six key values observed to be significant to job satisfaction will be described.

Freedom

A noteworthy theme that surfaced was the employees' recurring appreciation for the autonomy they are given to shape their workday within the established policies and guidelines of the municipality of Amsterdam. This aspect emerged as an important value that contributes significantly to job satisfaction, as employees can adjust their activities to what they perceive as necessary and align them with their individual preferences and needs. For instance, certain neighbourhoods were sometimes skipped if they appeared to be clean. Additionally, one of the workers stated, "If you know a team is coming afterwards you can leave some litter, but suppose you are in a quiet neighbourhood where employees of the department Schoon do not come by every day, then I take more." Therefore, the first key value emphasised by the employees is the ability and freedom to shape their own activities independently.

Variety

Another prominent recurring theme that emerged from the interviews and observations was the employees' appreciation for the variety that characterises their workday. Specifically, the respondents noted that they are assigned different tasks and routes each day and work with different teams, resulting in a fresh and stimulating experience on a daily basis. The opportunity to engage in various activities, such as sweeping or operating a sweeper, further amplifies the diversity and dynamism of their work. Hence, the second key value that contributes to employee satisfaction is the presence of variety in their job duties.

Working Outdoors

Furthermore, many of the employees expressed a strong affinity for working outdoors, citing it as a significant factor in their job enjoyment. This observation is understandable given the numerous other themes that are associated with outdoor work, including variety, freedom, and the ability to engage in social interactions. Given its perceived importance to employee well-being, this aspect was considered as another key value, and is thus identified as the third element that contributes to employee satisfaction: the ability to work outdoors.

Social Interactions

Another insight is that employees frequently expressed their enjoyment of their work, highlighting positive social interactions with colleagues, residents, and tourists as contributing factors. Many noted that their work is constantly dynamic, making it never dull. Thus, the fourth key value of the employees of department Schoon is social interactions at work, fostering positive relationships with co-workers and people in the urban environment. However, they also acknowledged that negative moments do occur, such as dealing with angry traffic participants or receiving complaints about their work. One cleaner also said, "Sometimes I get complaints about the quality of my work, citizens say I work for them because my pay is their tax money." Nonetheless, during the walk-along sessions, the employees were generally met with positive reactions from most individuals, with occasional compliments being received.

Interestingly, the employees noted that people on the street sometimes prefer to seek their assistance for information or directions rather than go to the police if they are also present. According to the employees, the reason for this is probably that they are perceived as more approachable and less authoritative. The employees also noted that they were regarded as signposts of the municipality of Amsterdam and thus received increased attention, and were expected to rise above conflicts when they arose. Additionally, it was interesting to observe that tourists occasionally treated the employees of department Schoon as a noteworthy sight or attraction in Amsterdam, as they wanted their picture taken with them.

Dislike of Physically Demanding Tasks

The recurring theme among employees is that the employees tend to dislike the more physically demanding tasks. As noted by Steehouwer (2022), "the heavier the task, the lesser the task is liked." Therefore, the fifth key value for the department Schoon is the general dislike of physically demanding tasks. Notably, a few employees have expressed reluctance to continue working as cleaners until retirement age, citing the physical demands associated with the job as a primary concern. Moreover, some employees have highlighted the mental demands of their work, particularly when sweeping near traffic, which requires a high degree of attention to safety.

Tangible Results

Moreover, a recurring theme that emerged was the frustration expressed by the employees, regarding the quick reversal of their cleaning efforts, resulting in dirty streets the very next day despite their hard work. This situation sometimes leaves employees feeling as though their hard work has been for nothing. However, the majority of employees acknowledge that the satisfaction derived from turning a dirty street into a clean one and seeing tangible results usually outweighs the temporary frustration. As such, the sixth key value of the department Schoon is the importance attributed to perceiving tangible results, as this generates a sense of purpose and fulfilment among employees, as they observe that their efforts are contributing towards the beautification of Amsterdam.

Challenges Faced by the Department Schoon

During the observations, several challenges faced by employees of the department Schoon were identified, which could provide valuable insights into how a robot could be of assistance. These challenges include communication challenges, workforce shortages, reduced efficiency and complex traffic situations.

Communication Challenges

Although the workers demonstrated a high level of expertise in completing their tasks and displayed a deep knowledge of the routes they took, with minimal verbal communication among each other, effective communication between workers outside of cleaning tasks was not always achieved. For instance, there was a delay in the arrival of a sweeper truck because the employees did not have each other's contact information. It was noted by the employees that this kind challenge of communication appeared frequently. Furthermore, the timing of sweeping is critical due to the wind, and close cooperation between the sweeping team and the Ravo operator is essential for a seamless cleaning process.

Labour Shortage

A recurring issue that was frequently discussed was the impact of budget cuts on the workforce, contributing to labour shortages in the department. Due to limited resources, few new employees are hired when vacancies arise. In addition, some older employees who are no longer able to perform physically demanding tasks are still classified as such on paper, resulting in a higher number of employees performing these heavy tasks on paper than in reality.

The aforementioned challenge of the impact of budget cuts on the workforce is closely linked to another frequently cited issue, which is the high rate of absenteeism among workers, which further exacerbates the high labour shortage in department Schoon. Physically demanding tasks such as lifting and disposing of heavy waste bags in garbage trucks are usually carried out by young men and are often cited as one of the reasons for absenteeism, as they can develop physical ailments over time due to the heavy strain on their bodies. This in turn exacerbates the problem of staff shortages, forcing the department to hire temporary replacements from employment agencies.

Reduced Efficiency

These temporary replacements, hired to fill in for absent employees in the department, often lack experience and familiarity with the demands of the job. As a result, they require guidance and instruction, which can have a negative impact on the efficiency of the department.

Typically, employees of department Schoon work based on their experience, as mentioned before, with limited communication among themselves, which makes it even more difficult for temporary workers to work alongside them. On occasion, cleaning teams express a preference not to have substitutes, as this affects their cleaning efficiency. As a participant observer, I can empathise with this view, as I sometimes found it challenging to keep up with the cleaning team and understand where I needed to go.

Furthermore, the accumulation of waste next to the containers poses a logistical challenge for the department Schoon. Before waste trucks can empty the containers, the waste next to the containers must be removed manually, leading to traffic congestion and inefficiency in the waste collection process. In addition, the accumulation of litter next to household waste bags placed on public streets also poses a challenge, as the tight schedules of the employees sometimes mean that they do not have enough time to remove the litter left on the ground next to the bags due to their high workload.

In addition, the process of emptying the bins is inefficient as it requires an employee to manually empty each bin. This process involves getting out of the vehicle at each bin, emptying the contents and driving to the next bin, which is a time-consuming task.

Furthermore, several employees reported being frustrated by equipment maintenance issues, such as the lack of time to clean the sweepers between jobs, reducing the effectiveness of the Ravo (a sweeper). During the observations, there were also instances of blockages caused by large objects, such as a pizza box, resulting in temporary traffic disruption.

Complex Traffic Situations
Another challenge is posed by Amsterdam's bustling traffic environment, presenting obstacles for effective waste management. Employees engaged in this task are frequently exposed to dangerous situations when working on the streets, requiring them to exercise extreme caution to avoid accidents. Furthermore, during the walk-along sessions, the Ravo sweeper sometimes lost traction on slippery roads, leading to traffic delays and complex scenarios where cars were signalled to reverse.

Conclusion Department Schoon
In the context of department Schoon, it has been observed that the majority of employees exhibit a high level of job satisfaction, with a set of six key values contributing to this satisfaction, illustrated in Figure 17. These values include the freedom to shape their own activities, a variety in job duties, the ability to work outdoors, social interactions with colleagues and individuals in the urban environment, a preference for tasks that are not physically demanding, and the perception of tangible results. To ensure job satisfaction and acceptance of robots in this department, it is necessary to maintain these values. However, it is important to recognise that the introduction of any technology may require certain incremental changes that may compromise some values. Such changes should be made discreetly and carefully to ensure that job satisfaction.

In addition to their core responsibility of maintaining cleanliness in the city, employees in the department Schoon are observed to play a significant social and supportive role in the urban environment of Amsterdam, as individuals often seek their assistance for directions or other queries. However, the department Schoon faces multiple challenges, as illustrated in Figure 18, which includes communication challenges, labour shortage, decreased efficiency, and the challenge of navigating complex traffic situations.

One area of particular concern is employee absenteeism, as this indirectly reduces the efficiency of department Schoon. The root cause of this absenteeism is mainly attributed to physically demanding tasks, such as lifting and unloading heavy trash bags into garbage trucks, which can cause physical ailments over time. This results in the need to hire temporary replacements from employment agencies, who may lack the requisite experience and familiarity with job requirements, resulting in reduced efficiency of department Schoon's teams. A robotic solution can prove beneficial in this context, provided it can optimise the efficiency of the waste management and address the issue of physical workload and labour shortages, thereby reducing the burden on employees.

The implementation of robots in the department Schoon presents several challenges, including autonomous navigation in the busy and complex traffic environment of Amsterdam, addressing the complexity of waste removal in hard-to-reach areas, and adapting to the limited communication style of employees, which may hinder effective collaboration between humans and robots. These factors pose significant challenges for robots to perform cleaning tasks independently or in collaboration with a team, if that is the robot's designated task.

Figure 17. Six illustrated key values that are important for the job satisfaction of the employees of department Schoon. These need to be safeguarded when developing and implementing a robot in the department to ensure continued job satisfaction of the employees.

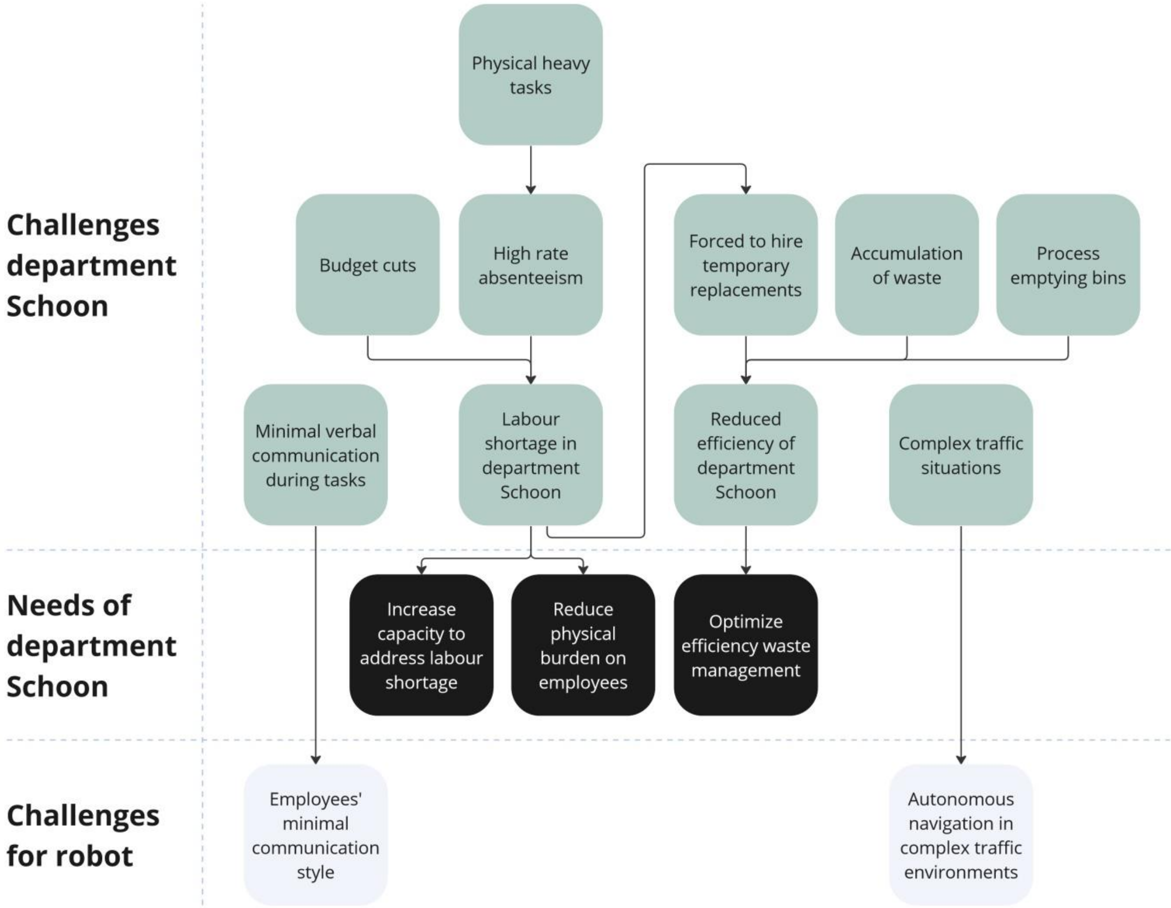


Figure 18. An overview of the challenges faced by department Schoon, including the needs of the department and the challenges associated with implementing a robotic solution. The analysis reveals that physically demanding tasks are affecting the efficiency of the department, leading to the need for a robot that can alleviate this burden and increase operational capacity. This overview provides a summary highlighting the main points and interrelationships. It should be noted, however, that there may be other elements, as it mainly reflects the broad outlines.

3.4 Developments City of Amsterdam

In order to develop an effective robotic solution to Amsterdam's waste management challenges, and as the development and implementation of a robot will take time, it is necessary to consider the future context in which the robot will operate. This requires an understanding of how the city of Amsterdam will develop over the next decade. To provide a comprehensive overview of this future context, this section will elaborate on the general developments that will impact the city, as well as those specific to Amsterdam. Detailed insights will be provided into both of these areas, as well as an examination of the future vision of the municipality and the developments it will bring forth, which will further shape the Amsterdam of the future.

General Developments in Cities

In order to gain a thorough understanding of the external environmental factors that will affect Amsterdam and its urban environment in the near future, this section will provide an elaboration on the developments that will have a significant impact on urban life in Amsterdam.

Smart Mobility

When a robot navigates through Amsterdam, it will interact with various traffic participants. To understand what traffic will look like in several years in Amsterdam, an understanding of mobility trends is required that may influence the future of urban transportation. McKinsey & Company (2017, 2021) argues that there will be a shift to intelligent mobility within the next decade. This prediction suggests that almost all vehicles will be linked to the internet and powered by electricity, enhancing safety on roads. (ESPAS, 2019)

Furthermore, McKinsey & Company (2021) states that the number of autonomous vehicles will increase significantly in ten years, and Elon Musk, CEO of Tesla, has announced that he will produce autonomous robot-taxis by 2024. (Jackson, 2022) In an optimistic future scenario, the sight of self-driving vehicles carrying passengers and goods would be commonplace. Such intelligent technologies make mobility more efficient and sustainable. (McKinsey & Company, 2022) A negative side effect of autonomous vehicles could be that the streets become more occupied (Mckinsey & Company, 2017), but as these vehicles are predicted to function with higher efficiency, this will not automatically lead to more traffic congestion. (Zakharenko, 2016)

However, autonomous vehicles face significant challenges, such as regulations, safety, and consumer acceptance, as well as the capacity to handle unpredictable traffic scenarios. (Litman, 2017) As a result, the literature is divided on the prospects of autonomous vehicles dominating traffic in ten years. Nonetheless, the technology is under constant development, and significant investments are being made to support its growth. (Holland-Letz et al., 2017)

Increasing Presence of Technology

In the upcoming years, an increasing amount of products will be connected to the internet, a trend commonly known as the Internet of Things. As a result, technology will play a more significant role in our daily lives, leading to a more digitised society and greater datafication. (ESPAS, 2019; Marr, 2021) In addition, it is predicted that cities will increasingly generate data, which can be used to manage the urban environment with the assistance of AI, resulting in a more manageable and efficient city. (FreedomLab, 2021) Next to that, the implementation of 5g networks allows for faster connectivity and low latency, enhancing the data flow. (McKinsey & Company, 2022) This increasing connectivity and availability of data provides opportunities to address challenges in, for example, waste management. (ESPAS, 2019; Bibri & Krogstie, 2020)

Additionally, robots are expected to become more commonplace in our daily lives the coming years, particularly in areas such as package and food delivery (Meili Robots, 2022), as well as in our homes (FutureLearn, 2021). The Robots-as-a-Service (RaaS) trend accelerates these developments, making robot adoption more affordable and accessible to businesses. (Meili Robots, 2022)

Sustainability of Increasing Importance

The challenges posed by climate change (ESPAS, 2019) and resource depletion (PwC, n.d.) are expected to continue to impact our daily lives in the upcoming years, requiring urgent societal solutions, such as the adoption of sustainable or circular systems that optimise the use of existing materials while minimising emissions. (Winston, 2019) The Netherlands has set a target of achieving climate neutrality by 2050, and to this end, it is introducing more sustainable regulations aimed at reducing specific types of waste. For example, in 2023, deposits on cans will be implemented, and by 2030, all packaging must be recyclable and contain a minimum percentage of recycled materials. (Kort, 2022) These regulations add to the current measures, which include deposits on plastic bottles, a ban on single-use plastic packaging, and a 10-cent charge for plastic bags. (Ministerie van Infrastructuur en Waterstaat, n.d.-b)

In line with governmental initiatives aimed at promoting more sustainable practices, an increasing number of individuals are adopting more sustainable lifestyles as they become more environmentally aware. (Deloitte, 2022) One observable manifestation of this trend is that products are increasingly being reused, repaired or refurbished instead of being disposed of as residual waste. (StartUs Insights, 2023-a)

The Ongoing Labour Shortage

The labour shortage in the Netherlands is currently a concern (SBB, 2020), and it is estimated that by 2030, there will be a labour shortage of half a million people in the Netherlands. (Personeelsnet, 2018) The ageing population in the Netherlands will also contribute to the labour shortage as the number of elderly people increases. (Sociaal en Cultureel Planbureau, 2019, AD, 2022) This ageing trend has also a negative impact on labour migration in the EU, implying that the shortage cannot be entirely resolved with migrants, as in the past. (Jansma, 2022)

Specific Developments in Amsterdam

Beyond the general trends that impact Amsterdam, several city-specific factors shape its future. One such factor is urbanization, whereby more individuals are expected to reside in cities. Amsterdam is projected to have over 1 million inhabitants by 2030, representing a 22% growth rate. (Statista Research Department, 2022) This demographic shift will lead to a higher population density and a more crowded Amsterdam. In addition, the projected recovery and increase in tourism after the COVID-19 pandemic

(UNWTO, 2022; Gemeente Amsterdam, 2022a) in Amsterdam are likely to contribute to the city's crowdedness.

As Amsterdam continues to grow in population and visitors, traffic is expected to increase, along with an increase in the amount of generated waste. (Gemeente Amsterdam, 2021) To address these and other emerging challenges, the municipality of Amsterdam has developed a future vision that will further shape the city. The following section provides an overview of the developments planned by the municipality to meet the challenges that Amsterdam will face.

Developments Arising from Amsterdam's Future Vision

In order to gain a more comprehensive understanding of Amsterdam's future outlook for the next decade, it is necessary to examine the range of developments that will arise in Amsterdam as a result of the city's future vision. These developments, which are expected to significantly shape Amsterdam's future, complement and build on those already discussed in the previous sections.

To provide a more nuanced understanding of Amsterdam's future prospects, this section will undertake an analysis of the city's future vision and policies. This will be achieved through an examination of the municipality's published materials concerning their future vision. Accordingly, the subsequent section will explore the specific developments that will follow from Amsterdam's future vision, and the ways in which these developments will shape the city's outlook in the years ahead.

Increasing Emphasis on Sustainability in Municipal Policies

In response to the pressing concerns and issues related to global warming and resource depletion, Amsterdam aims to take significant measures to improve the city's sustainability, as reflected in the municipality's Environmental Vision for 2050. This vision of increasing emphasis on sustainability is reflected in several areas of Amsterdam, including the adoption of clean and renewable energy sources, and the goal of achieving circularity by 2050. (Gemeente Amsterdam, 2021) To realise these objectives, Amsterdam seeks to reduce the use of new raw materials by 50% and become emission-free by 2030. (Gemeente Amsterdam, 2022b) For instance, the municipality intends to limit the use of internal combustion engine cars and allow only electric vehicles on the A10 inner ring road by 2030. (NOS, 2019) This sustainable emphasis is also reflected in the practice of waste management, as Amsterdam has implemented, or is exploring, a range of strategies to promote more sustainable waste management practices, which will be discussed in more detail in Chapter 3.5.

Reducing Car Usage

To address the challenges related to Amsterdam's growth, such as traffic congestion and to further increase sustainability in the area of mobility, the city is proactively taking measures and envisaging a future mobility plan. This plan aims to reduce car usage by 25% and promote alternative modes of transport, such as water transportation. This approach is crucial to support Amsterdam's growth while avoiding traffic congestion and without discouraging car usage, the city's already congested streets would be unable to cope. (Gemeente Amsterdam, 2021) In addition, Amsterdam aims to create car-free zones and eliminate there about 1,700 parking spaces in the city centre by

2025. (Gemeente Amsterdam, 2020a) Throughout the whole city, more than 10,000 parking spots will be removed. (Ruimte voor Lopen, 2023) This additional space will be repurposed to enhance the city's green infrastructure, promoting resident well-being and making the city more resilient to heat. (Gemeente Amsterdam, 2021)

Moreover, due to the old and weak bridges and quays in the centre of Amsterdam (NOS, 2021), the municipality has implemented in 2021 a ban on vehicles heavier than 30 tonnes in the city centre, as a measure to relieve the strain on the bridges and quays. (Gemeente Amsterdam, 2021) To further ease the burden on the old infrastructure in the centre, the municipality is actively exploring alternative waste management solutions to the standard 25-tonne waste collection trucks, which will be discussed in more detail in Chapter 3.5. (Gemeente Amsterdam, 2020a)

Establishment Hubs

To further proactively promote sustainable transportation and decrease car usage in Amsterdam's city centre, the municipality is formulating plans to allocate space to transportation hubs the upcoming years. The objective is to enhance accessibility throughout the city, while taking into account the expected increase in the movement of people and goods. These hubs will serve as interconnectors between various modes of transportation such as smaller and low-emission vehicles, public transport, and water transportation, with the aim of improving accessibility. This shift to alternative modes of transportation is critical as the number of passenger cars and heavy trucks will be reduced in Amsterdam, as mentioned before. The logistics hubs will be strategically located in areas that are easily accessible to trucks, providing multiple functions, serving not only personal transportation but also logistical planning. (City of Amsterdam, 2021)

Fostering Resident Involvement

To effectively address the challenges and anticipated developments in Amsterdam in the coming years, the city's future vision emphasises the involvement and motivation of residents, enabling them to play a more significant role in the management and development of the city. The municipality's philosophy of "Samen Stadmaken" (together we make the city) underpins this approach, which aims to foster a sense of ownership and responsibility among residents towards the city of Amsterdam. (Gemeente Amsterdam, n.d.-g) The focus on greater resident involvement is also evident in the municipality's exploration of various strategies to tackle the growing waste problem and promote sustainable waste management practices among residents, which will be discussed in further detail in Chapter 3.5.

Conclusion Developments Amsterdam

To provide a more concrete comprehension of the anticipated developments that are likely to shape the future of Amsterdam, Figure 19 presents an overview of these developments, including the associated challenges, the future vision of Amsterdam to cope with these challenges and developments, as well as the needs and opportunities that may arise from them.

As technology continues to evolve, it is likely to play an increasingly significant role in our daily lives, including in mobility, as autonomous driving technology is advancing rapidly. However, uncertainty is associated with autonomous driving technology, and it remains uncertain to what extent autonomous vehicles will dominate Amsterdam's streets in the coming decade. Meanwhile, robots are expected to become more commonplace in our daily lives, particularly in areas such as package and food delivery and our homes. The RaaS trend is making robot adoption more affordable and accessible to businesses, further accelerating their presence. However, given the uncertainty associated with autonomous driving technology, it is essential to consider this factor when developing a robot. For instance, if the robot's task involves navigating through traffic, it is crucial to explore how to achieve this autonomously.

In addition, as cities, including Amsterdam, are predicted to generate increasing amounts of data the coming years, there is a growing potential to leverage this data to address waste management challenges more effectively. The advent of 5G networks further amplifies this potential, as it enables faster connectivity and reduced latency, thereby enhancing the speed and efficiency of data transmission. This increased capacity and transmission of data can facilitate the development of valuable insights and solutions for more efficient waste management and can be of potential when developing a robot.

In addition to technological developments, other factors such as demographic ageing and significant labour shortages are also likely to impact Amsterdam's future prospects. It is estimated that the Netherlands will face a labour shortage of approximately half a million people by 2030. This predicament could potentially negatively impact several sectors, including the department Schoon, which is already facing labour shortages, as discussed in Chapter 3.3. Thus, a robotic solution that can increase capacity without the need for additional workforce could be of value to the municipality of Amsterdam.

Furthermore, as Amsterdam's population is expected to grow by 22% by 2030, and together with the city's growing tourist industry, it will lead to significant challenges such as the increasing amount of waste and traffic congestion. To address these challenges and manage the city's growth, the municipality of Amsterdam has formulated a future vision with several measures that shape the city's future. Central to this vision is emphasis on sustainability, as concerns and problems associated with global warming and resource depletion are growing. The municipality of Amsterdam shares the national goal of transitioning to a circular economy by 2050, with the first step being to reduce raw materials by 50% and become emission-free by 2030. The shift to a circular economy requires efficient waste management to minimise waste's loss of value and usability, leading to a growing need for more sustainable and efficient waste management practices in Amsterdam. Therefore, a robotic solution which aligns with the sustainability objectives (e.g. emission-free) and can contribute to more sustainable and efficient waste management practices would be of great value to the municipality of Amsterdam.

In addition, to promote a more sustainable mobility in Amsterdam and to manage the city's expected growth and increasing traffic congestion, Amsterdam plans to reduce car usage by 25% and parking sports, establish car-free zones in the city centre by 2025, and promote alternative modes of transportation. To remain accessibility in certain areas of Amsterdam and to ensure sustainable transportation in the face of Amsterdam’s growth, the city plans to create transportation hubs that connect various modes of transportation. This establishment of car-free zones in the city centre and the creation of transportation hubs represent significant opportunities for the robot, as they facilitate the creation of additional space and enable the implementation of new modes of transportation.

To enhance Amsterdam's ability to effectively tackle the challenges it will face in the coming years, one of the objectives highlighted in the municipality's future vision is to increase resident involvement, recognising that the city's success depends greatly on the collective contributions of its inhabitants. Consequently, the municipality is exploring approaches to involve residents more in the management and development of the city to foster a sense of responsibility and ownership among them. Resident ownership is also necessary in achieving a more sustainable economy, as this requires everyone's efforts. Resident involvement is also further reflected in Amsterdam’s exploration of waste management strategies to encourage greater participation and responsibility among residents; this will be discussed in more detail in Chapter 3.5. Therefore, a robotic solution that promotes greater resident involvement and ownership will be of significant value to the municipality of Amsterdam.

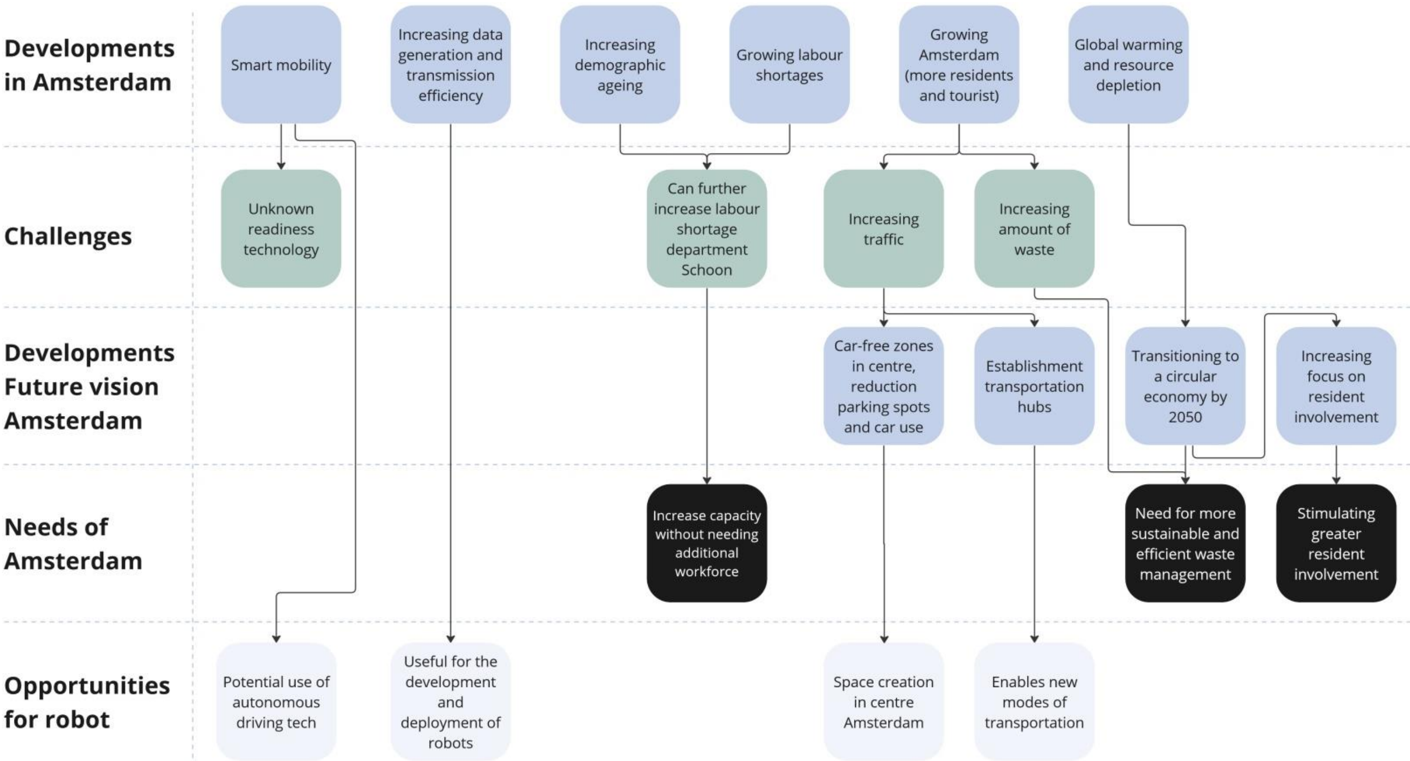


Figure 19. Illustration of how the expected developments in Amsterdam present different challenges, which in turn create specific needs and opportunities, which will be used in this thesis to design a robotic solution that can be of value to Amsterdam. This overview provides a concise summary highlighting the main points and interrelationships. It should be noted, however, that there may be other elements, as it mainly reflects the broad outlines.

3.5 Developments Waste Management Amsterdam

Currently, the annual waste production in Amsterdam is approximately 358 kilograms per person. With an anticipated increase in population, the total amount of waste is expected to increase as well. The city is currently facing challenges in maintaining a clean environment, and this challenge is expected to intensify due to the projected growth in population and tourism the coming years. Furthermore, factors such as global warming, increased emissions, and resource depletion have prompted Amsterdam to adopt a circular economy by 2050. (Gemeente Amsterdam, n.d.-f) In a circular system, waste is considered as a resource, and to achieve circularity, it is essential to improve the value and usability of waste. This requires the implementation of more sustainable and efficient waste management and recycling solutions.

Consequently, the municipality of Amsterdam is exploring and assessing more effective waste management approaches to address these challenges in the years ahead. The city's future vision shapes these explorations, with an emphasis on increasing sustainability in the waste management practices and increasing resident engagement in the waste management.

To determine how a robot can be integrated into this evolving waste management framework, it is necessary to examine the developments in waste management practices in Amsterdam. This section provides a comprehensive overview of Amsterdam's evolving waste management priorities and strategies.

Improving Waste Separation and Recycling

Amsterdam aims to achieve a circular economy by 2050, which entails treating waste as a valuable resource for the production of new products. To achieve this, it is essential to improve waste separation, as only then materials can be reused. (Gemeente Amsterdam, 2020a) As 37% of residual waste in Amsterdam is organic, which can be recycled completely, the municipality aims to increase the availability of organic waste containers throughout the city by 2025, in order to increase the amount of waste being recycled. (Gemeente Amsterdam, 2021b)

To further improve the waste separation, Amsterdam has introduced a post-consumer waste separation system for PMD since 2017, as it is more effective and sustainable than traditional methods and can separate PMD far better than humans. (Gemeente Amsterdam, n.d.-h) This system enables the extraction of more valuable resources before the remaining waste is incinerated, promoting a more cost-effective and sustainable waste separation method in the long run. (Gemeente Amsterdam, 2021b) However, one of the drawbacks of post-consumer recycling is that it may reduce people's awareness of waste production and eliminate the positive experience associated with separating waste. For this reason, Amsterdam employed both the consumer and post-consumer recycling methods until 2021, and from then on, it has switched to exclusively using the post-separation system for PMD. As a result, the containers previously used for PMD collection are now used for other types of waste. (BNNVARA, 2016; Gemeente Amsterdam, 2020a)

Implementing Innovative Technologies in the Waste Management

To further enhance the efficiency and sustainability of the waste management, Amsterdam is adopting innovative technologies in the waste practices. Amsterdam has implemented internet connected waste containers powered by solar energy, such as Mr. Fill, that compresses waste and signal when they are full. Additionally, image recognition techniques are employed in Amsterdam to automatically detect street cleanliness levels, and an app is being developed that will enable department Schoon employees to monitor container locations and report waste issues via iPads. These various applications are being combined and integrated into a data infrastructure system to optimise the flow of data and provide deeper insights into the waste stream. (Gemeente Amsterdam, 2021b) By connecting waste management elements to the internet, generated data can inform predictive waste flow mapping and dynamic waste collection, improving efficiency. (StartUs Insights, 2023b). This approach addresses limitations of traditional fixed trash collection schedules, such as emptying empty bins or leaving overflowing bins for extended periods.

Exploring New Ways of Waste Collection and Transportation

Currently, in areas where underground containers cannot be placed due to insufficient space and weak quays and bridges that cannot hold the trucks used to empty underground containers, garbage bags are placed on the streets and collected by garbage trucks. However, this approach has a range of negative consequences, such as traffic congestion, excessive strain on the weak quays and bridges, high CO_2 emissions, and litter accumulation on the streets. (Gemeente Amsterdam, n.d.-i) As a result, in line with Amsterdam's future vision, which includes the prohibition of heavy vehicles in the city centre and the pursuit of alternatives to the current heavy waste collection vehicles, the city is investigating alternative waste collection methods aimed at addressing these challenges and promoting sustainability.

One of the trials being conducted involves small garbage trucks that deposit bags into an electric boat for transportation over water to a collection site for processing, see Figure 20. (Gemeente Amsterdam, n.d.-j) While this approach offers the benefits of a 90% reduction in CO_2 emissions and reduced disturbance to residents compared to regular trucks, there are some drawbacks. Participants reported an increase in the perception of uncleanliness due to waste bags being left on the street overnight, and litter was observed to remain on the street for an extended period after collection as people believed the sweeping was not being done quickly enough after trash collection. Additionally, the boat has been criticised for producing unpleasant smells and noise during docking and waste disposal. Another issue is that the use of smaller trucks results in longer collection times, as less waste can be collected, and trucks need to make more trips to pick up everything, leaving bags on the street for longer. (Gemeente Amsterdam, n.d.-j)

Another trial involves the use of an electric cargo bike for trash collection by appointment, see Figure 21. The findings of this study indicate that there has been a reduction in the amount of litter on the streets, resulting in a cleaner neighbourhood; 73% of those surveyed reported that the area was cleaner than before the implementation of the trial. Furthermore, waste separation has increased by 21%, and there has been a decrease in the incidence of pest-related problems. The majority of respondents expressed a preference for waste collection at home, as it facilitates easier separation of waste. However, there are areas that require improvement. The time slots are perceived as too broad, resulting in long wait times for residents. Furthermore, the absence of evening slots has also been noted as a concern. Another critical issue that requires attention is the degree of inclusiveness of this form of waste collection, as some participants have reported difficulty in registering their waste. (Gemeente Amsterdam, n.d.-b)

A forthcoming project in Amsterdam is an innovative underground waste transport system in the Sluisbuurt area, illustrated in Figure 22, aimed at optimising waste disposal and eliminating the need for street containers, thereby reducing the number of garbage trucks on the road. (Gemeente Amsterdam, n.d.-c) However, the convenience of the system may cause people to lose sight of their waste generation and consider it an inconsequential issue. This attitude could stimulate littering behaviour, as highlighted by the waste management behavioural framework, which emphasises the importance of awareness regarding the negative consequences of waste in reducing such behaviour. Additionally, the implementation of such a system may prove too difficult or expensive in existing neighbourhoods. Thus, the long-term effectiveness of this system in addressing the waste problems remains to be seen.

Currently, the Amsterdam Institute for Advanced Metropolitan Solutions (AMS Institute) and the Massachusetts Institute of Technology (MIT) are developing together a novel project called the Roboat. This project represents an innovative robotic solution that aims to address the waste management challenges faced by Amsterdam. The Roboat will be designed to navigate the city's canals in an autonomous manner, both independently and as part of a swarm of other Roboats, to collect litter from the canals and act as a floating trash bin, as illustrated in Figure 23. (Benson et al., 2021) Waste can be separated in the Roboat, creating one location instead of people having to separate waste in multiple places, streamlining the waste disposal process and making it more convenient for people to dispose of their waste in the right place. The intended ability of the Roboat to autonomously transport waste to a collection point when full can increase the efficiency of the waste disposal flow. The researchers of this project argue that this waste system could serve 70% of all the districts in Amsterdam. (AMS Institute, n.d.) However, legislative challenges and privacy concerns must be addressed before the Roboat can be implemented. (The Guardian, 2021) Furthermore, due to Amsterdam's regulations, which stipulate a maximum walking distance of 75 metres to a waste container, with the possibility of extending this to 125 metres if necessary (Overheid.nl, 2018), the Roboat may not be a feasible solution in all areas of the city, as not all areas are within 125 metres of the water.

Figure 20. The municipality of Amsterdam is conducting a trial of small garbage trucks that deposit bags into electric boats. This initiative is part of the municipality's search for alternative waste collection methods that can address the current challenges of waste collection in the city centre. Image taken from Gemeente Amsterdam. (n.d.-j).

Figure 21. Amsterdam is also conducting trials where trash collection in the city centre is done by appointment, using an electric cargo bike. This trial is also part of the municipality's efforts to find alternative waste collection methods that can effectively address the current challenges faced in the city centre. Image taken from Gemeente Amsterdam (n.d.-a).

Figure 22. An innovative underground waste transport system is set to be implemented in a neighbourhood in Amsterdam, with the aim of optimising the city's waste management. Image taken from de Brug (2020).

Figure 23. While the Roboat has the potential to provide a novel and effective solution for waste collection and transportation in Amsterdam, it is important to note that certain areas of the city, including neighbourhoods in the city centre, are outside the maximum walking distance of 125 metres to a waste container from the waterfront. Image taken from Roboat (n.d.).

Motivating and Involving Residents More in Waste Management

As Amsterdam's future vision aims to further encourage resident ownership, several strategies are being explored or implemented to promote more sustainable waste management behaviour among residents. One such strategy is reflected in the city's current slogan, "Together we keep our city clean," as seen in Figure 24, which reinforces this position of resident responsibility. Other communication tools, such as flyers, informational signs, and "green graffiti" are used to further stimulate ownership and awareness. Campaigns are also conducted to promote correct waste disposal behaviour, such as the message to make cardboard smaller before putting it in containers. (Gemeente Amsterdam, 2021b)

Additionally, Amsterdam actively engages residents by providing opportunities for them to contribute to waste reduction efforts, including participating in litter pickups, adopting waste containers, or signing up for street and playground maintenance. (Gemeente Amsterdam, n.d.-e) Amsterdam's Plastic Smart City program, which focuses on mitigating plastic pollution by involving the community in joint problem-solving, adopting a chain approach, raising awareness, and promoting education, is another current strategy. (Gemeente Amsterdam, 2020b)

To further support the effort of stimulating resident responsibility, the municipality is conducting trials that involve making waste containers more visually appealing by surrounding them with planters, to reduce misplaced trash in the neighbourhood and the feeling of anonymity, see Figure 25. (Van Zoelen, 2020) Research indicated that visually appealing bins can effectively reduce littering behaviour. (Lyndhurst, 2012) Additionally, nudging tactics are being employed, such as painting footsteps on the street leading towards waste containers to subconsciously encourage people to dispose of their trash in the correct location. (Het Centrum voor Criminaliteitspreventie en Veiligheid, 2016)

Figure 24. The municipality of Amsterdam utilises the slogan, "Samen houden we onze Stad Schoon" (Together we keep our city clean), as a means to promote a sense of collective responsibility among all individuals residing in or visiting Amsterdam. Image taken from Gemeente Amsterdam (n.d.-d).

Figure 25. In Amsterdam, trials are being conducted to increase the visibility and attractiveness of underground waste containers, aiming to promote residents' sense of responsibility to reduce misplaced waste and minimise anonymity, as this can contribute to littering behaviour. Image taken from Van Zoelen (2019).

Moreover, enforcing regulations to encourage correct waste disposal behaviour is another approach used by the municipality of Amsterdam, although the literature suggests that this approach may not be entirely effective since it relies on negative motivators. (Lyndhurst, 2012) Nevertheless, waste enforcement remains a useful tool to some extent.

Conclusion Developments Waste Management Amsterdam

To address the challenge of maintaining a clean environment in Amsterdam, especially in light of the anticipated population and tourism growth, the municipality is exploring various waste management strategies. This is expected to result in significant developments in the waste management practices in Amsterdam in the coming years. A graphical representation of the analysis of waste management developments in Amsterdam can be found in Figure 26.

With a growing concern for sustainability and the city's objective to achieve circularity by 2050, the emphasis is on making waste management practices more sustainable and efficient. A key aspect of this effort involves enhancing waste separation and recycling in Amsterdam through increasing the availability of organic waste containers and the implementation of post-consumer PMD separation systems. Compared to consumer separation methods, this approach is cost-effective and sustainable, leading to higher resource retrieval, which is essential for a circular economy. However, a potential drawback of this method is a possible decrease in individuals' awareness of their waste production and the positive experience associated with waste separation.

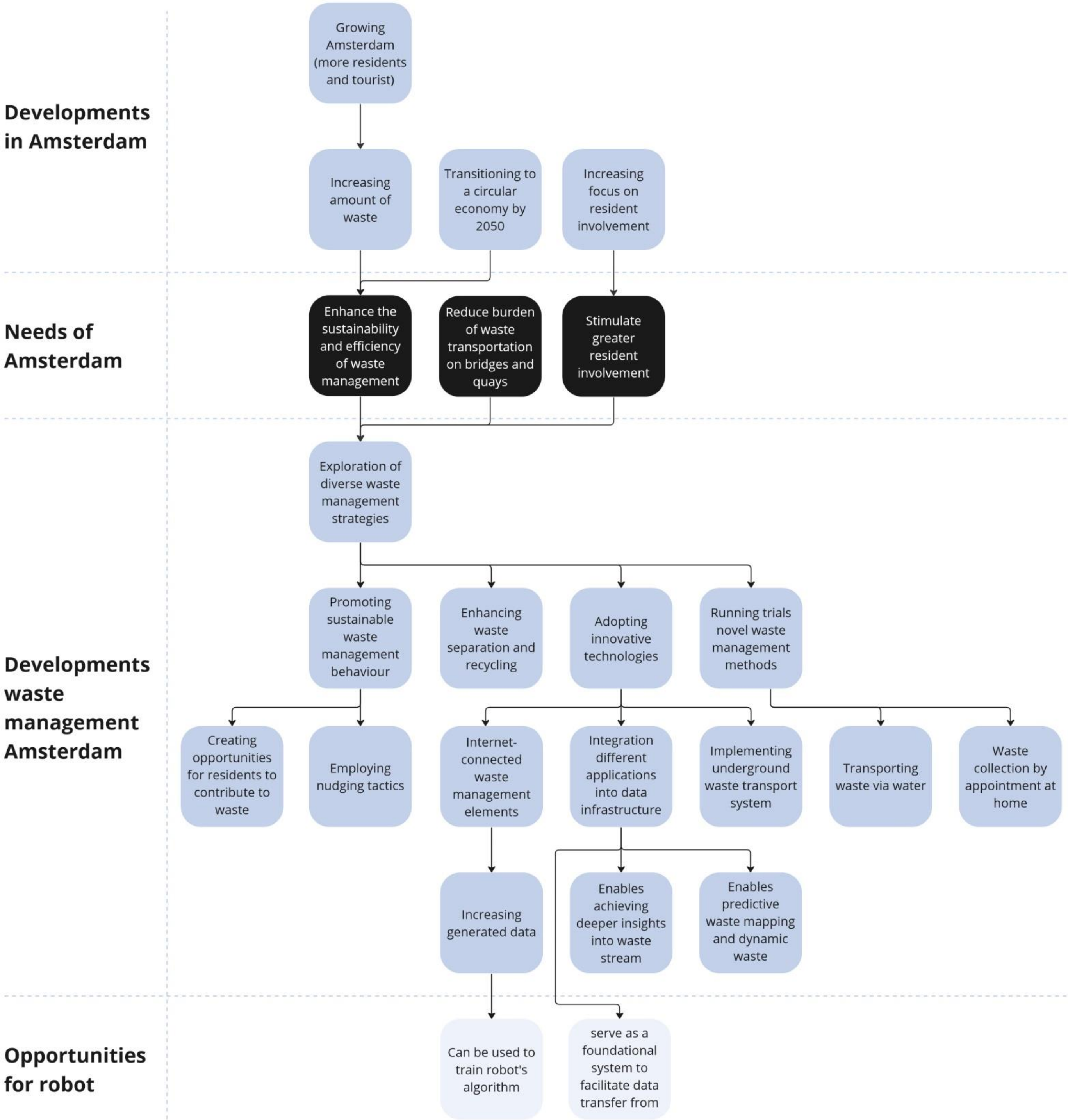


Figure 26. A graphic illustration to offer a clearer understanding of the advancements in waste management practices in Amsterdam. These advancements are influenced by the aforementioned developments in Amsterdam and present potential opportunities for the robot. As the Roboat is not an initiative of the municipality of Amsterdam, it is not included in the visual. This overview provides a concise summary highlighting the main points and interrelationships. It should be noted, however, that there may be other elements, as it mainly reflects the broad outlines.

To further enhance efficiency and sustainability, the city of Amsterdam is adopting innovative technologies such as internet-connected waste containers powered by solar energy, which compress waste and signal when they are full. In addition, image recognition technology is being used to automatically determine street cleanliness, and an app is being developed that will allow employees to monitor container locations and report waste problems. These various applications will be integrated into a new data infrastructure system to optimise data flows and gain deeper insights into the waste stream in Amsterdam. By connecting waste management components to the internet, the collected data can facilitate predictive waste flow mapping and dynamic waste collection, leading to significant efficiency improvements. The establishment of a data infrastructure in Amsterdam's waste management, in addition to the increase in generated data related to waste, provides a valuable opportunity for the development and deployment of a robot. This data can be used to train the robot's algorithm, while the infrastructure itself can serve as a foundational system to facilitate data transfer from the robot.

In addition, to enhance the efficiency and sustainability of waste collection and transportation practices, and alleviate stress on weak bridges and quays, the municipality is exploring alternative methods. One such trial involves the use of small garbage trucks that deposit bags into an electric boat for transportation, which reduces disturbance and CO_2 emissions. However, this approach may result in increased uncleanliness due to bags left on the street overnight and litter left uncollected for too long. The boat has also received criticism for producing unpleasant smells and noise during docking and waste disposal, and the use of smaller trucks results in longer collection times, leaving waste bags on the street for an extended period. Another trial involves the use of electric cargo bikes for trash collection by appointment, which has resulted in a reduction of visible litter, an increase of waste separation, and a decrease of pest-related problems. However, participants reported that the time-slots were perceived as too broad, and difficulty in registering their waste was reported, which reduced inclusiveness. Another innovative underground waste transport system will be implemented in Amsterdam, which aims to optimise waste disposal and eliminate the need for street containers, thereby reducing the number of garbage trucks on the road. However, the convenience of the system may result in people losing sight of their waste production, and the implementation may prove too difficult or expensive in existing neighbourhoods. The long-term effectiveness of this system in addressing the waste problem in Amsterdam remains to be seen. Another project under development is the Roboat, intended to operate as an autonomous robot, collecting litter from Amsterdam's canals and serving as a floating trash bin. Its primary objective is to streamline the waste disposal process by autonomously transporting waste to a designated location, ultimately increasing efficiency. Nevertheless, the implementation of the Roboat is subject to privacy and legislative challenges that must be addressed. Furthermore, regulatory constraints regarding the maximum walking distance to a waste container may make the Roboat unfeasible in certain areas of the city.

Furthermore, the municipality of Amsterdam is striving to improve the efficiency and sustainability of its waste management practices by adopting a more proactive approach to tackle waste accumulation. To this end, various strategies have been implemented or are being explored to promote sustainable waste management behaviours among residents, with the aim of fostering a sense of resident ownership and involvement in waste management. Opportunities for residents to contribute to waste reduction efforts have been made available, and a range of nudging tactics have been utilised, including the deployment of visually appealing waste containers and the placement of directional markings on streets leading to waste containers, all aimed at encouraging proper waste disposal behaviour.

Given the growing waste challenges in Amsterdam, there is a need for more sustainable and efficient waste management practices in the coming years. In this regard, a robot that can further improve the efficiency and sustainability of waste collection, transportation or separation could be valuable to the municipality of Amsterdam. The same applies to a robot that can promote ownership and good waste management behaviour among residents, as this is in line with the municipality's future vision objective to motivate residents to participate. Similarly, the implementation of a robotic waste management solution in the centre of Amsterdam can be beneficial if it can reduce the strain and pressure on the fragile bridges and quays, which is another objective of the city's future vision for its waste management.

3.6 Conclusion Context Analysis Amsterdam

The aim of this conclusion is to provide a comprehensive overview of the context analysis of Amsterdam, which will serve as a basis for the design of a robot that can contribute to a cleaner Amsterdam. In order to achieve this objective, the chapter will present conclusions on various topics, including an analysis of Amsterdam's waste management challenges, the key values and challenges of the department Schoon, the developments in Amsterdam over the next decade, and the developments in its waste management practices. In addition, the chapter will identify the requirements and opportunities for the robot that emerge from this contextual analysis.

Three Major Waste Challenges Amsterdam

The present challenge of meeting the cleaning targets in Amsterdam is causing significant inconvenience to the residents. An analysis of the waste challenges in Amsterdam has identified three primary waste issues, each presenting complex challenges with distinct origins. A visual representation illustrating this analysis is provided in Figure 15 in Chapter 3.2.

The first issue concerns the presence of waste bags on the streets, which can be attributed to waste management policies allowing individuals to dispose of waste bags in public areas in the city centre. This leads to litter accumulation and incentivises littering behaviour. The second issue is the accumulation of waste next to containers, resulting primarily from inefficient waste management practices, such as containers remaining full for a long time, leading to residents being unable to dispose of their trash. This, in turn, stimulates littering behaviour and further exacerbates waste accumulation in Amsterdam. The accumulation creates logistical challenges and additional inefficiencies in the waste collection process for the department Schoon, leading to increased traffic congestion. In contrast, the third issue of litter on the streets, which occurs mainly in the heavily polluted city centre, primarily results from complex human littering behaviour. The high influx of tourists in this area presents an additional challenge given their short stay, making it difficult to effect behavioural change as this is a time-consuming process.

The first two issues, trash bags on the streets and waste next to containers, result mainly from inefficiencies in waste management, incentivising littering behaviour among individuals. On the other hand, the third issue of litter on the streets in Amsterdam primarily results from human behaviour. Therefore, it can be challenging for a single robotic solution to tackle all waste problems simultaneously.

Department Schoon Six Key Values and Challenges

The municipal urban cleaning department of Amsterdam, known as the department Schoon, is dedicated to maintaining a clean urban environment in the city. In addition to their cleaning duties, the employees also play a vital social and supportive role as they are frequently approached by individuals seeking directions or other assistance. The current level of employee job satisfaction is high and can be attributed to six observed key values, including the freedom to shape their activities, the diversity of job duties, the opportunity to work outdoors, social interactions with colleagues and individuals in the urban environment, a preference for tasks that are not physically demanding, and the perception of tangible results. To ensure continued job satisfaction and successful implementation of robots in the department, it is essential to preserve these values. However, it is important to acknowledge that the introduction of new technology may require incremental changes that could potentially compromise these values. Therefore, any modifications should be carefully implemented to ensure that job satisfaction among the employees of department Schoon.

However, the department Schoon faces multiple challenges. A visual representation of the interrelationship between the department's challenges and the corresponding needs and challenges for the robot is shown in Figure 18 in Chapter 3.3. The department's challenges include communication challenges, labour shortages, reduced efficiency, and navigating complex traffic situations. One area of particular concern is employee absenteeism, as this indirectly reduces the efficiency of department Schoon. The root cause of this absenteeism is mainly attributed to physically demanding tasks, which can cause physical ailments over time. This results in the need to hire temporary replacements who lack experience and familiarity with the job requirements, which reduces the efficiency of Schoon's teams. This finding suggests that a robot that can help reduce these physically demanding tasks could help reduce absenteeism due to physical ailments, thereby indirectly increasing efficiency.

The introduction of robots into the department Schoon poses additional challenges, including autonomous navigation in Amsterdam's complex and busy traffic environment, waste removal in hard-to-reach areas, and adapting to the limited communication style of employees. These challenges make it difficult for robots to perform cleaning tasks independently or in collaboration with the department's teams.

Sustainable and Growing Amsterdam

The municipality of Amsterdam is currently facing challenges in meeting their cleaning targets, leading to significant inconvenience for residents. With a projected 22% population growth by 2030 and an increase in tourism, the volume of waste and related challenges is expected to rise. Consequently, there is a pressing need for a more efficient waste management system to address these issues. In addition, due to environmental problems, sustainability is becoming an increasingly important focus in the municipal policies of Amsterdam, with the city aiming to achieve circularity by 2050, whereby waste will be reused as a resource. This will require improved and sustainable waste separation and collection management systems in the coming years to minimise the loss of value and usability of waste. A visual overview of the interrelationship between Amsterdam's developments, challenges and needs can be found in figure 19 in Chapter 3.4.

However, demographic aging and significant labour shortages make it increasingly challenging to address the waste problem by relying solely on additional workforce, as the department Schoon is already facing workforce shortages. As a result, implementing a robotic solution to optimise processes, increase capacity, and reduce the need for additional workers can offer added value to the city of Amsterdam in addressing the growing waste problem and making waste management more efficient.

Furthermore, to promote a more sustainable mobility in Amsterdam and to handle the city's expected growth and increasing traffic congestion, Amsterdam aims to establish car-free zones in the city centre by 2025, and promote alternative modes of transportation. Additionally, the city plans to create transportation hubs that connect various modes of transportation to remain accessibility in certain areas of Amsterdam and to ensure sustainable transportation in the face of Amsterdam's growth. The implementation of car-free zones in the city centre and the establishment of transportation hubs present opportunities for the robot. These initiatives not only allow for the creation of extra space in the centre but also facilitate the introduction of new modes of transportation that can be integrated.

Technological advancements, such as rapid developments in autonomous driving technology and increasing use of robots in our daily lives, are expected to play an increasingly significant role in the city's future prospects. Although the extent to which autonomous vehicles will dominate Amsterdam's streets remains uncertain, the advent of 5G networks and the increased generation of data present a potential to facilitate the development of valuable insights and solutions for more efficient waste management, thereby helping to address the waste challenges the city faces.

Increasing Efficient and Sustainable Waste Management of Amsterdam

In order to address the challenges of maintaining a clean environment in Amsterdam, particularly in light of the expected growth in population and tourism, and the city's objective to achieve circularity by 2050, the municipality is actively exploring a range of waste management strategies to improve the efficiency and sustainability of their waste management practices. A visual representation of the analysis of waste management developments in Amsterdam can be found in Figure 26 in Chapter 3.5.

The waste management developments in Amsterdam include increasing the availability of organic waste containers throughout Amsterdam, as well as developing and implementing a variety of technologies to optimise the collection, transportation, and processing of waste. Examples of these waste management innovations include internet-connected waste containers, the use of image recognition techniques to automatically assess the cleanliness of streets, the creation of an app to monitor container locations and report waste issues, the implementation of more sustainable and effective post-consumer PMD separation systems, the integration of various applications to optimise waste data flows and generate more in-depth insights into the waste stream, the utilization of waste data to predict waste flow mapping, and the implementation of dynamic waste collection schedules.

In addition to adopting innovative technologies to improve the waste management, the municipality of Amsterdam is exploring new approaches to improve the efficiency and sustainability of waste collection and transport infrastructure. These efforts aim to address the growing waste challenges while also alleviating the strain on the city centre's fragile bridges and quays, which cannot sustain current waste management methods in the long run. The municipality is currently conducting various trials, including the use of small garbage trucks that deposit bags into an electric boat for transportation. While this approach reduces disturbances and CO_2 emissions, it leads to increased uncleanliness due to bags left on the street overnight, litter left uncollected for too long, noise, and unpleasant odours produced by the boat, as well as longer collection times. Another trial involves the use of electric cargo bikes for trash collection by appointment, which has yielded a reduction in visible litter, an increase in waste separation, and a decrease in pest-related problems. However, the time-slots were deemed too broad, and registering waste proved challenging, resulting in reduced inclusiveness.

Another innovative waste transportation infrastructure being implemented in the Amsterdam is an underground waste transportation system. The system is aimed at optimising waste disposal and eliminating the need for street containers, ultimately reducing the number of garbage trucks on the road. However, the convenience of the system may lead to people losing sight of their waste production, and its implementation may prove too difficult or expensive in existing neighbourhoods. As a result, the long-term effectiveness of this system in addressing Amsterdam's waste challenges remains to be determined. Furthermore, another innovative waste transportation involves the development of the Roboat, a project of AMS Institute and MIT in Amsterdam. This autonomous robot is designed to collect litter from Amsterdam's canals and serve as a floating trash bin, transporting waste to a designated location. However, the implementation of the Roboat is subjected to privacy and legislative challenges. Additionally, regulatory constraints related to the maximum allowable walking distance to a waste container may make the Roboat unfeasible in certain areas of the city.

To further enhance the efficiency and sustainability of Amsterdam's waste management practices, the municipality is taking proactive measures to address the waste problems, including addressing littering behaviour, which has been found to be a major contributor to the city's waste problems. To this end, various strategies have been implemented or are being explored to promote sustainable waste management behaviours among residents, with the objective of fostering a sense of resident ownership and involvement in waste management, which is also highlighted in the municipality's future vision as it is essential in achieving a more sustainable economy. Opportunities have been made available for residents to contribute to waste reduction efforts, and a range of nudging tactics have been employed, such as deploying visually appealing waste containers and placing directional markings on streets leading to waste containers. These efforts are all aimed at encouraging proper waste disposal behaviour.

Overall, the municipality of Amsterdam is committed to exploring a range of innovative waste management strategies to address the growing waste challenges and promote sustainable waste management practices, to achieve a cleaner city and achieve its circularity objective by 2050. Introducing a robot capable of enhancing waste collection, transportation, and separation can benefit the municipality, along with promoting resident ownership and relieving strain on the city centre's infrastructure.

Requirements and Opportunities for the Robot

In order to develop a robotic solution that meets the specific needs of the city Amsterdam, the municipality, and the department Schoon, a detailed list of requirements has been established based on the conclusions outlined in this chapter. Table 1 provides an overview of these requirements, along with an explanation of why they are essential. Furthermore, as some developments in Amsterdam offer opportunities for the implementation of a robotic solution, a corresponding list of these opportunities and their rationale has been compiled and can be found in Table 2.

Given the identified waste challenges facing Amsterdam, as well as the anticipated developments in the city, it is necessary to carefully consider the robot's task. To this end, it is necessary to evaluate the potential capabilities of robots over the coming decade in order to determine what tasks the robot can accomplish. This evaluation will be further explored in the following chapter. Additionally, since the robot will likely interact with humans in various settings, including the urban environment and department Schoon employees, it is crucial to design these interactions with care. To ensure that these interactions are positive, the following chapter will examine the factors that contribute to positive human-robot interactions.

	Requirements	Why
Needs Amsterdam	**Achieve cleaning targets**	Achieve cleaning targets will help make Amsterdam more liveable
	Improve waste management efficiency	Growing waste challenges in Amsterdam require more efficient waste management solutions
	Improve waste management sustainability	Amsterdam's sustainability objectives and growing waste challenges require more sustainable waste management solutions
	Reduce waste transportation burden	The bridges and quays in the city centre are weak and Amsterdam aims to alleviate the burden
	Promote resident ownership	An objective of the municipality's future vision to address challenges of the city
Needs department Schoon	**Increase capacity without additional manpower**	Increasing labour shortage, demographic ageing in the Netherlands and workforce shortage in department Schoon, requires increasing capacity without requiring additional workforce
	Safeguard key employee values	Robot implementation can influence employee's job satisfaction, therefore the key values need to be safeguarded
	Reduce task-related physical burden	Heavy physical tasks may lead to absenteeism and reduce efficiency of department Schoon
Feasibility robot development	**Address limitations autonomous driving**	To increase feasibility, limitations of autonomous driving technology in a busy Amsterdam should be considered in the design phase
Correct waste disposal behaviour	**Address littering behaviour tourists**	Increase of tourists with own waste behaviour in the city centre may require a different approach because of their short stay
	Address littering behaviour	Littering behaviour is a major contributor to waste problems in Amsterdam
	Enable waste disposal at will	People are not always able to throw away their trash whenever they want, stimulating littering behaviour
	Stimulate proper waste disposal behaviour	As littering behaviour is a major contributor to waste problems in Amsterdam, proper waste behaviour should be stimulated
	Prevent waste bags on streets	Preventing waste bags from being put on the streets in the first place can reduce waste accumulation and littering behaviour stimulation
Regulations in Amsterdam	**Emission-free**	Only emission-free vehicles will be allowed in the city center
	Comply with regulation max. walking distance container	To comply with the municipal guideline of a maximum walking distance of 75 metres to a waste container

Table 1. Based on the conclusion of this chapter a detailed list of requirements is presented to develop a robotic solution that can meet the specific needs of Amsterdam, the municipality and department Schoon.

Opportunities	Why
Establishment car-free zones in city centre	Creates more space in the city centre
Establishment transport hubs in Amsterdam	Can be used for waste transportation
Increasing generated data in Amsterdam and waste	Can be used to train algorithm of robot
Establishment data infrastructure in waste management	Can provide a basis for when a data infrastructure is needed when employing a robot

Table 2. The table illustrates a list of potential opportunities for the robot, which can significantly contribute to its successful use and facilitate the development of a more customised and optimal robotic solution.

4

Literature Review
Developments in Robotics and Key Factors Human-Robot Interaction

4 Literature Review Developments in Robotics and Key Factors Human-Robot Interaction

The municipality of Amsterdam is currently faced with the challenge of maintaining a clean city and is considering the potential application of robotics to address the waste management challenges. To determine how a robot can be of value and its task in addressing the identified waste problems, it is necessary to conduct a comprehensive literature review of the potential capabilities of robots over the next decade. Furthermore, to provide a more accurate and thorough assessment, it is crucial to consider the potential challenges that may arise as robotics technology evolves. The methodology for conducting this literature review can be found in Chapter 4.1 and the examination of the developments and challenges in robotics can be found in Chapter 4.2.

In addition, given the likelihood of robots interacting with humans in the urban environment and employees of the department Schoon, it is crucial to investigate the factors in the literature that influence successful human-robot interaction (HRI). This will enable the design of a more suitable interaction in the robot of this thesis, facilitating a more seamless and efficient collaboration between humans and robots in Amsterdam. The analysis of the HRI key factors can be found in Chapter 4.3.

In order to gain valuable insights and inspiration into the current application of the HRI factors in robots, an exploration will be conducted into existing robots utilised in the field of waste management. The literature offers various definitions of robots, with Olaronke et al. (2017) defining a robot as a “reprogrammable, physically embodied, intelligent and mobile system that is energy driven and has the ability to act autonomously or be teleoperated in an environment which it has the capability to sense.” Alternatively, an entity can be defined as a robot when it perceives its environment, processes the information and takes action accordingly. (Tiddi et al., 2020) However, as Amsterdam is in need of additional capacity to address its waste management challenges, a robot can also be defined as a mechanical entity that assists with the waste management. As some non-robotic solutions, according to the definition in the robotics literature, contain interesting HRI features that are worth exploring, the latter definition of robots (as defined by the author of this thesis) is used. Chapter 4.3 discusses this exploration in more detail.

Overall, the primary objective of the literature review in this chapter is a comprehensive exploration of advancements in robotics and the key factors that contribute to successful HRI. Chapter 4.4 provides a conclusion of the findings in this regard. This comprehensive understanding is important for designing a more feasible robot that can contribute to a cleaner Amsterdam.

4.1 Method

In order to achieve a comprehensive understanding of the potential capabilities of robots in the near future, a comprehensive literature review has been conducted, encompassing the developments and challenges in the field of robotics. This review takes into account the challenges associated with robotic advancements, as they can significantly impact the pace of progress in this field. The primary objective of this investigation is to gain a clearer insight into the expected capabilities of robots and determine how they can be utilised to address the waste challenges of Amsterdam.

In addition, a comprehensive investigation into the key factors that influence successful HRI has been conducted through a thorough review of the literature on the developments, acceptance, and ethical concerns related to HRI. This investigation incorporates fields such as psychology and sociology to provide a deeper understanding of human behaviour towards robots. The primary objective of this investigation is to gain a clearer understanding of the expected nature of HRI in future contexts and identify ways to facilitate a positive HRI in the robot of this thesis.

4.2 Developments in Robotics

In response to the request from the municipality of Amsterdam to explore the potential value of using robots to address waste management challenges, it is necessary to understand the anticipated capabilities of robots in the near future to effectively design their tasks. To achieve this, a detailed review of relevant literature will be conducted to gain insights into the expected advancements and emerging trends in robotics, along with potential challenges that may influence the capabilities of robots. The subsequent sections will provide a detailed exposition of these developments and challenges.

Increasing Adaptability of Robots to Complex Environments

One of the technological advancement that has the potential to greatly enhance the capabilities of robots is the improvement of machine learning, a subset of AI that enables robots to adapt and respond to complex and unpredictable situations without human intervention. This is made possible by the robot's operating system, which acts as its 'brain', and with the rapid development of various drivers such as data, algorithms, and computation, the possibilities of machine learning are increasing at a fast pace. (Agrawal, 2021) As a result, robots are becoming increasingly capable of adapting and responding to complex situations without the need for supervision, which is particularly relevant in the complex environment of Amsterdam.

In addition, the significant increase in computing power (Huawai, 2021) is also contributing to the adaptability of robots by enabling faster processing of data (Gardner, 2022), while reducing computing costs. (Agrawal, 2021) The implementation of 5G networks is further enhancing the transmission and processing of data, particularly for cloud-based networks (Lässig et al., 2021), which can lead to smaller and more affordable robots as the computing takes place in the cloud. (Guizzo, 2011) Furthermore, the growing number of internet-connected products generates more data annually, and it is estimated that yottabytes of data will be produced by 2030. (Huawai, 2021) In addition, as cities generate an increasing amount of data in the coming years as well

(FreedomLab, 2021), more training data will be available to train algorithms, which will, in turn, enhance robots' ability to manage the complexity of their environment. (Agrawal, 2021) In Amsterdam, this development of an increase of generated data is visible, among others, in the waste management infrastructure, where more internet-connected products generate data about waste flow.

Recent advancements in swarm technologies, facilitated by more efficient and cost-effective hardware (Yang et al., 2018), enable greater adaptability in robot operations and enhanced cooperation among robots through the sharing of tasks and communication, which further adds to the capability and adaptability of robots. (Lässig et al., 2021)

While increasing advancements in autonomous technologies have the potential to improve the capabilities of robots (McKinsey & Company, 2015, 2022), the extent to which autonomous driving technology will be developed in a decade remains uncertain, given the challenges associated with planning and acting in complex environments. Moreover, current robot technology still faces significant difficulties in dealing with uncertain environments and acting accordingly. (Tiddi et al., 2020) The level of autonomy, i.e. the ability to perform tasks without human intervention and to adapt to their environment (Etemad, 2002), that robots will be able to achieve in a decade remains uncertain and challenging. (Campbell et al., 2010; AMS Institute, 2021) This challenge is particularly significant in Amsterdam's complex and dynamic environment, where robots have to navigate unpredictable situations, posing a fundamental challenge for the development of an autonomous robot.

Increasing Cost-Effective Robots

The cost of training AI has significantly decreased, by a factor of 100 between 2017 and 2019, (Wang, 2020) as has the training time, and along with other developments in the field of robotics, it is anticipated that robots will become more cost-effective in the near future. (Atkinson, 2019) This will enhance the applicability of AI technology across different industries. (Agrawal, 2021; Clark & Perrault, 2022) The growing trend of Robots-as-a-Service further contributes to this by making robot implementation more accessible and affordable in businesses. (Meili Robots, 2022)

Furthermore, there are predictions that the cost of hardware components, including chips, will decrease in the coming years. (Diamandis, 2020) However, the uncertainty surrounding the duration of the on-going chip shortage may affect costs in the near term. (McKellop, 2021) Additionally, the cost of batteries is expected to decrease over the next decade, further reducing the overall cost of robotics. (Levin, 2022) Nevertheless, battery technologies that are both long-lasting and affordable, while simultaneously ensuring safety in use, pose a challenge for robots to navigate their environment effectively. (Yang et al., 2018)

Automation Replacing Human Jobs

Advances in artificial intelligence and related technologies have expanded robots' capabilities to engage with humans and perform various tasks, including hazardous or less desirable ones. (Lässig et al., 2021) Consequently, there is a prediction that low-skill and low-wage jobs will gradually be replaced by robots, with up to 20 million manufacturing jobs lost to robots and automation by 2030. Additionally, jobs involving repetitive tasks or transportation are likely to be automated in the near future. (Lardieri, 2019)

While creating a single robot to perform extensive tasks is cost-prohibitive, the use of robots is becoming increasingly attractive for high repetitive tasks as it is more cost-effective than employing humans in the long run. Robots can outperform human services and have the potential to enhance the availability and quality of services, as well as address societal problems like the aging population and labour shortages. However, it should be noted that while the use of robots is expected to increase in tasks that require mechanical, analytical, and intuitive intelligence, they are not yet capable of replacing humans in areas where empathic intelligence is critical. Therefore, it is unlikely that every service will be dominated by robots, as complicated emotional-social tasks will continue to be performed by humans or in collaboration with robots. This is because the emotional intelligence of robots is not yet sufficient to express genuine and "real" emotions. (Wirtz et al., 2018)

The trend of Robots-as-a-Service is expected to drive the adoption of robots in businesses, as it enhances the affordability and accessibility of robots. (Meili Robots, 2022) Other drivers such as wage increases and labour shortages are also anticipated to stimulate the adoption of automation in the coming years, as robots become more cost-effective and can alleviate the increasing workload resulting from the shortage of employees. (Lässig et al., 2021)

Conclusion Developments Robotics

In order to provide a clearer understanding of the relevant expected developments and challenges in robotics, an overview is illustrated in Figure 27. The advancements in machine learning, increasing connectivity, computing power, swarm technology, autonomous driving technology, and the rise in available training data are expected to enhance robots' ability to autonomously navigate complex urban environments in the coming years. This presents an opportunity for the deployment of an autonomous robot in the complex dynamic city of Amsterdam. However, while technological advancements have the potential to greatly enhance the capabilities of robots, the fundamental difficulties of coping with unpredictable environments remain challenging. As a result, the extent to which a robot can achieve full autonomy in Amsterdam remains uncertain.

Another opportunity arises from the predicted cost-effectiveness of robot labour in certain areas, such as manufacturing, transportation, and repetitive jobs. This is due to the reduction in the training costs of AI, the decreasing costs of hardware components, and the increasing capabilities of machine learning and other technologies. The growing trend of Robots-as-a-Service further increases accessibility and affordability of robot implementation. As a result, integrating a robot into department Schoon of the municipality of Amsterdam may be more feasible in the near future.

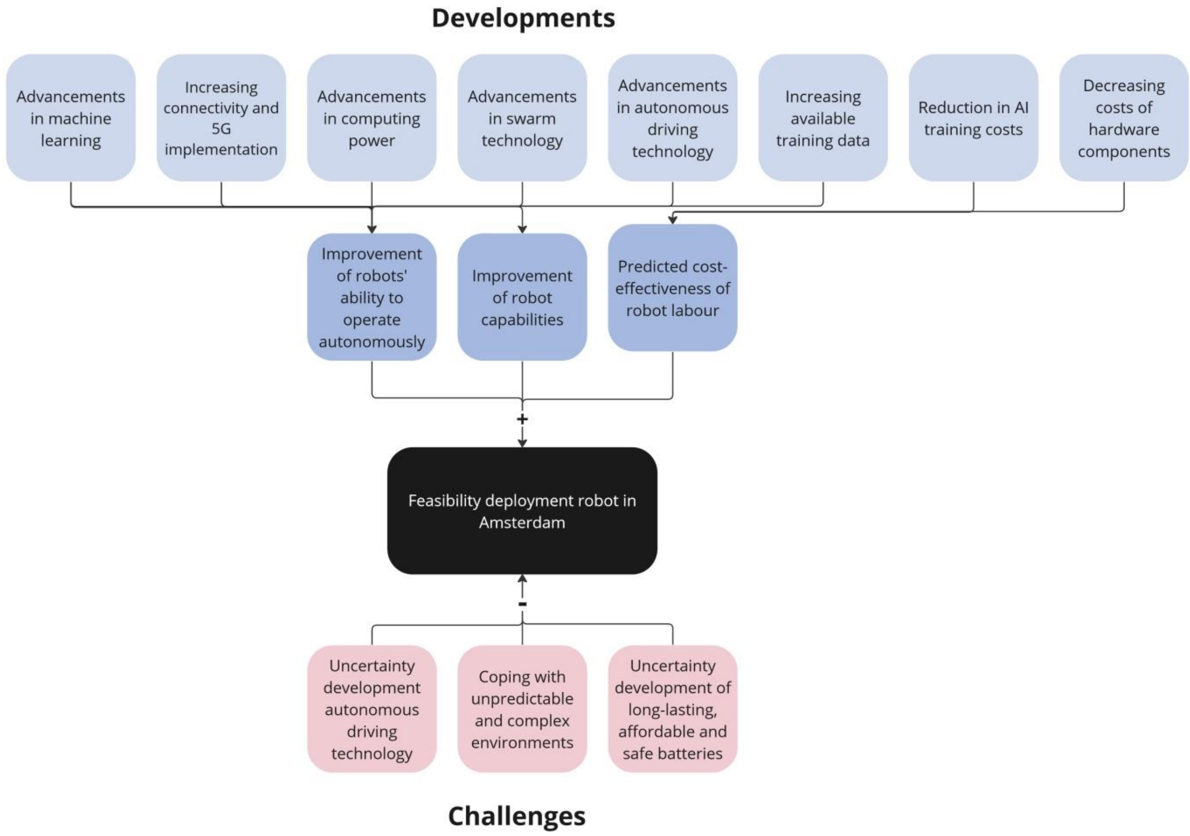


Figure 27. This illustration is intended to provide an overview of the developments and challenges in robotics that influence the feasibility of deploying robots in Amsterdam. It should be noted, however, that there may be other elements, as it mainly reflects the broad outlines.

Moreover, advancements in AI have expanded robots' capabilities to perform various tasks, including hazardous or repetitive ones. The implementation of automation in high-frequency tasks is becoming increasingly feasible and cost-effective, leading to technology playing a more significant role in our working lives. Consequently, it is predicted that low-skill and low-wage jobs may gradually be replaced by robots, with up to 20 million manufacturing jobs predicted to be lost to automation by 2030. The adoption of automation is expected to be driven by, among others, Robots-as-a-Service, wage increases, demographic ageing, and labour shortages the coming years. In light of the challenges faced by department Schoon, such as heavy workloads and labour shortages, the implementation of robots could provide a valuable solution.

4.3 Key Factors Human Robot Interaction

When a robot is deployed in Amsterdam, it is highly likely that it will interact with humans, including those in urban environments or employees of the department Schoon. As autonomous robots moving in public spaces are still a rare sight, initial interactions can create a 'wow' effect, which is distinct from the eventual normalised experience. (Etemad, 2022) Therefore, building and shaping the relationship between robots and humans is necessary in order to ensure a successful robot implementation. To achieve this, it is crucial to design the human-robot interaction (HRI) in a positive manner that fosters efficient and seamless collaboration between humans and robots. The success of HRI depends heavily on the acceptance and trust of the robot by humans, which is necessary to achieve a shared goal. (Andriella et al., 2021)

Therefore, in order to shape a successful HRI in the robot of this thesis, the purpose of this section is to investigate and identify the key factors that stimulate a positive and successful HRI, as found in the HRI literature. Additionally, the following section will examine existing robots to determine how these HRI key factors are presently utilised in the interaction between robots and humans. This exploration aims to provide inspiration how these factors can be implemented in the robot of this thesis.

Literature Review Key Factors HRI

In order to shape a successful Human-Robot Interaction in the robot of this thesis, this section aims to present an overview of the influencing factors for a successful HRI based on a literature review. According to the literature, the acceptance of the robot by the users and their willingness to use it are crucial predictors of successful HRI. (Davis, 1989) Therefore, the factors influencing robot acceptance and intention to use are used to determine the success factor of the HRI. This thesis will refer to these factors as key factors of HRI and they can be categorised into two distinct groups, as illustrated in Table 3. An increase in the first group leads to higher robot acceptance and therefore a more successful HRI. (Schepers and Wetzels, 2007) However, an increase in the second group of key factors does not necessarily lead to a more successful HRI, as individuals' needs and wants may vary in different situations. Therefore, the robot should adapt and provide these factors in accordance with specific circumstances, and act in accordance with social, cultural, and functional norms. (Giebelhausen et al., 2014)

This is known as role congruency of the robot and, together with need congruency, leads to greater robot acceptance. (Soloman et al., 1985; Wirtz & Mattila, 2001) The key factors of HRI will be explained further on.

	Key factor HRI	Application
Increased quantity leads to improved HRI	**Perceived user friendliness**	Increasing readability of robot
		Increasing predictability of robot
	Perceived usefulness	Enhancing ability to adapt to changing environments and user's needs
	Subjective social norms	Adopting a collective positive attitude toward the robot
Needs and roles congruency	**Perceived humanness**	Using anthropomorphic aspects in appearance/behaviour
	Perceived social interactivity	Acting and displaying congruent emotions/social or human cues
	Perceived social presence	Creating a sense of a presence of another "being"
	Sense of safety and comfort	Defining responsibility for the robot's actions
		Addressing privacy
		Asking consent
		Providing transparency
		Addressing fear of job replacement
		Robot must act respectful
		Preventing people from feeling manipulated
	Perception of pleasantness and relationship	Using verbal cues or hand gestures
		Using personalizing aspects

Table 3. In order to gain a comprehensive understanding of the key factors that promote a positive human-robot interaction, a thorough overview is presented along with how these factors can be applied in a robot. These factors are categorised into two different groups, and it is important to note that an increase in the first group facilitates a more successful HRI, while the key factors in the second group must be aligned with the needs and roles of a specific context to avoid any negative impact on the HRI. (Davis, 1989; Bates, 1994; Duffy, 2003; Breazeal, 2003; Schepers & Wetzels, 2007; Heerink et al., 2008; Tinwell et al., 2011; Shin & Choo, 2011; Lee et al., 2012; Graaf & Allouch, 2013; Riek & Howard, 2014; Tan et al., 2016; Nomura & Kanda, 2016; Wilson et al., 2017; Yang et al., 2018; Wirtz et al., 2018; Tsiourti et al., 2019; Ghazali et al., 2020; Whillans et al., 2020; Fronemann, 2022; Song & Kim, 2022; Etemad, 2022)

Perceived User Friendliness
One of the key factors influencing the HRI is the perceived user friendliness, which is influenced by the readability and predictability of the robot. (Riek & Howard, 2014) To establish a more seamless interaction between the user and the robot, the user must be able to anticipate the robot's behaviour, which necessitates its actions to be consistent and, to some extent, predictable. This level of predictability and consistency is crucial to facilitate a better understanding of the robot, thereby enhancing the user's sense of autonomy and control, leading to a more positive HRI experience. (Fronemann, 2022)

Perceived Usefulness
Perceived usefulness is another influencing factor, defined as the extent to which a person believes using a robot will be beneficial for something they want to achieve. (Davis, 1989) The extent to which a person perceives a robot's adaptability to a dynamic environment and the user's evolving needs affects their perception of the robot's usefulness. (Shin & Choo, 2011; Graaf & Allouch, 2013) Ghazali et al., (2020) identified perceived usefulness as the most influential predictor of attitudes towards using a robot.

Subjective Social Norms
Subjective social norms, another key factor in HRI, refer to "a person's perception that most people who are important to him think he should or should not perform the behaviour in question." (Schepers & Wetzels, 2007) This factor influences the perceived usefulness of robots as well. When implementing a robot, it is important to consider social norms, and companies, in this case the municipality, can increase acceptance by adopting a collective positive attitude toward robot acceptance. (Schepers & Wetzels, 2007)

Perceived Humanness
The fourth factor, the perceived humanness of a robot, relates to the human tendency to attribute human-like characteristics to non-human objects. Research has shown that incorporating anthropomorphic aspects in the appearance or behaviour of robots can lead to more meaningful social interactions between robots and humans. (Song & Kim, 2022; Duffy, 2003)

The level of empathy towards a robot is significantly influenced by its anthropomorphic features, which in turn increases the intention to interact with the robot. (Tan et al., 2016) It is interesting to note that recent research has highlighted that when robots possess human-like voices, faces, or names, people tend to feel less comfortable or even guilty when the robots are given tasks like cleaning chores. (Whillans et al., 2020)

However, it is important to note that too much human resemblance in a robot can result in unrealistic expectations of its abilities, which can lead to disappointment when the robot makes an error (Duffy, 2003). The uncanny valley theory suggests that an overly human-like appearance or behaviour in a robot can appear unnatural and even frightening, especially when it is not convincingly realistic. (Mori et al., 2012) Furthermore, even small deviations from humanness can have a significant negative impact on the human-robot relationship. (Wirtz et al., 2018)

Taken together, these findings emphasise the importance of achieving an appropriate balance when incorporating anthropomorphic features into robot design to avoid adverse effects on the human-robot relationship.

Perceived Social Interactivity
In the context of human-robot interactions, individuals may unconsciously apply a social model to the robot, highlighting the importance of perceived social interactivity, as a fifth factor in HRI. This can be defined as the extent to which the robot's actions and emotions align with social norms, and is an important determinant of the quality of the interaction (Breazeal, 2003; Song & Kim, 2022). It is interesting to note that a robot does not have to look like a human to be considered capable in a social setting. (Bates, 1994)

The intention to use a robot will increase when a robot exhibits social or human cues. (Song & Kim, 2022; Etemad, 2022) However, the perceived intelligence and likability of a robot can be diminished if its emotional signals are inconsistent or incongruent, which reduces a person's ability to interpret these cues (Tsiourti et al., 2019). This underscores the importance of ensuring that a robot's social cues align with societal norms and expectations, in order to optimise its perceived social interactivity and enhance the quality of human-robot interactions.

Perceived Social Presence
The sixth key factor, the perceived social presence, concerns the extent to which the robot can elicit the feeling of being in the company of another “being.” (Heerink et al., 2008) When a robot can evoke this sense of presence, it has been observed to enhance robot acceptance. (Wirtz et al., 2018)

Sense of Safety and Comfort
The seventh influencing key factor in human-robot interaction is the sense of safety and comfort experienced by users during robot interactions. (Etemad, 2022) While incorporating anthropomorphic features can enhance the trustworthiness of robots to some extent, excessive human-likeness in appearance may elicit feelings of discomfort. (Tinwell et al., 2011) Ethical concerns surrounding robots have a significant influence on HRI, as emphasised by Wirtz et al. (2018), including issues related to privacy and transparency regarding data collection. (Heerink et al., 2010; Riek & Howard, 2014; Nomura & Kanda, 2016; Wirtz et al., 2018; Fronemann, 2022; Etemad, 2022)

Clearly defining responsibility for the actions and consequences of robots is essential to building trust and creating a sense of safety among humans. (Etemad, 2022) Fronemann et al. (2022) suggest that introducing any sensor used by a robot to the user and obtaining their consent before usage is essential. Additionally, respecting human dignity and ensuring the user's autonomy and control are other crucial factors that affect HRI. (Riek & Howard, 2014)

Additionally, the fear of job displacement by robots is a growing concern that requires consideration in the coming years, as this influences robot acceptance, as observed by Yang et al. (2018) and Etemad (2022). In addition, although robots with emotional abilities are perceived as more fun and credible in interactions, it is important to strike a balance to avoid feelings of manipulation by users. (Fronemann et al., 2022)

Perception of Pleasantness of Interaction and Relationship
According to Wirtz et al. (2018), a key aspect of the quality of HRI and the human-robot relationship is the perceived level of pleasantness. This perception can be influenced by various factors, such as verbal cues and hand gestures from the robot, as noted by Wilson et al. (2017). Furthermore, Lee et al. (2012) found that personalising aspects of the interaction can also positively affect the perception of pleasant HRI.

Key Factors HRI in Waste-Related Robots

As the robot of this thesis will interact with people in Amsterdam, the HRI needs to be designed. To this end, this section aims to examine the key factors of HRI that are currently being employed in robots, and to draw inspiration from them for the design of the HRI of the robot in this thesis. In order to ensure the relevance of the outcomes for this thesis, the selection of robots has been specified to robots that address waste-related issues. While not every robot discussed in this section meets the criteria for a robot as defined in the literature, some of the non-robotic solutions include interesting features worth exploring. Thus, the definition of what is considered a robot for the purposes of this exploration has been somewhat broadened and adjusted to include any mechanical entity that assists with waste management.

Moreover, given that the examined robots are involved in waste management, the framework of waste management behaviour from Chapter 2 will be utilised to examine how a robot can be employed to address waste management behaviour.

Relationships with Robots
In the present consumer market, there are only a few autonomous cleaning robots available, with the Roomba being a widely-recognised and accepted autonomous vacuum robot, as depicted in Figure 28. The Roomba's design focuses on key HRI factors such as perceived user friendliness and usefulness, making it an accessible and easy-to-use robot, as noted by Forlizzi (2007). Despite lacking human-like traits, a significant number of families have reportedly formed attachments to their Roombas, even treating them as members of the household. (NBC News, 2007) This phenomenon may be partially attributed to humans' tendency to anthropomorphise non-human objects, (New Scientist, 2020) which highlights that robots do not need to have anthropomorphic features for individuals to establish a connection with them. Additionally, many homeowners have modified their living spaces to facilitate the Roomba's movement, a practice referred to as "roombarization" (Sung et al., 2008). This example illustrates how humans may adapt to a robot's capabilities, rather than vice versa.

While the key factor of knowing that someone or something else will perform the cleaning can decrease perceived responsibility and potentially encourage laziness, which in turn could encourage littering behaviour, no evidence has been found in the literature to support this claim for the utilization of a Roomba. In fact, it has been noted that individuals can use the extra time afforded by the Roomba's autonomous cleaning to perform other tasks. (Forlizzi, 2007) However, this observation was made in a private home setting where individuals are responsible for their own households. It remains to be seen what the effects would be of such an autonomous cleaning robot in a public space, where individuals may already feel less accountable.

Addressing Concerns Regarding Job Replacement

As mentioned earlier, the prospect of being replaced by a robot can elicit fear among individuals. One company that aims to address this concern to increase the acceptance of their robot-product is the producer of Adlatus, an autonomous cleaning robot for buildings. The company seeks to communicate to employees that the robot is meant to be a tool to assist them in their work, freeing up time for other tasks, rather than a replacement for human labour. (Autonome Schoonmaakrobot Maakt Opmars, 2018)

Anthropomorphic Features to Increase Awareness and Recognition

Another interesting robot is Mr Trash Wheel, which is designed to intercept floating litter in the water, see Figure 29. The anthropomorphic features in its design are intended to increase awareness and recognition. Its main objective, apart from cleaning the water, is to raise awareness of the problem of litter, which is a key factor in encouraging proper waste management behaviour. However, Mr Trash Wheel also illustrates the importance of maintaining a balance when incorporating anthropomorphic elements. According to the creator of the wheel, people tend to see it as less serious because of its googly eyes. (Snow, 2017)

Figure 28. Despite lacking anthropomorphic characteristics, people tend to form relationships with a Roomba, suggesting that anthropomorphic features are not a necessary prerequisite for establishing a connection. Image taken from Carte (2020).

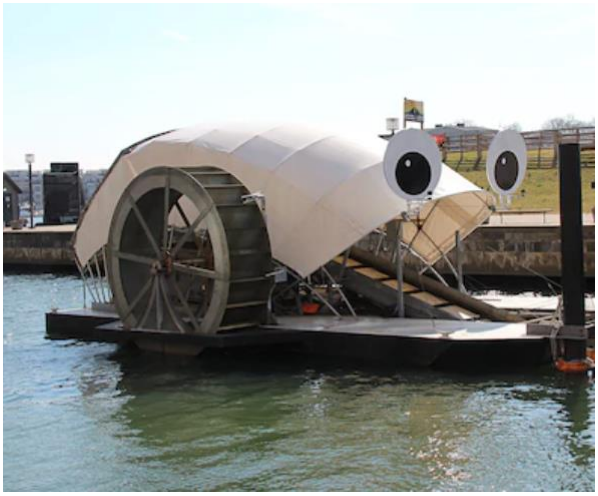


Figure 29. In addition to its primary function of cleaning water, the distinct anthropomorphic design of this robot also aims to raise awareness of the problem of litter. Noteworthy, this device also highlights the importance of using anthropomorphism with discretion, as the googly eyes may cause people to perceive it as less serious, as stated by its creator. Image taken from Snow (2017).

Engaging and Enjoyable HRI to Motivate Proper Waste Management Behaviour

The Deepest Trash Can, featured in a Volkswagen advertisement, is an interactive bin that produces a falling sound when trash is deposited into it, creating the illusion of a bottomless bin. This interaction was designed to make recycling experience more enjoyable and incentivise people to collect and dispose of trash in the garbage can. (Volkswagen, 2009) Results from a conducted experiment revealed that 41 kilograms more waste was collected in the Deepest Trash Can compared to a regular bin, demonstrating the effectiveness of fun as a positive motivator, nudging human waste management behaviour. (Creature & Co., n.d.) This example also highlights how the use of pleasantness in human-robot interactions, a key factor in HRI, can be used to promote proper waste management practices.

Holle Bolle Gijs, a widely known trash can situated at Efteling in the Netherlands, is another example of a bin that employs nudging techniques to encourage proper waste disposal behaviour, see Figure 30. Upon depositing trash, Holle Bolle Gijs expresses gratitude, triggering the brain's production of dopamine, a neurotransmitter that motivates and stimulates that particular behaviour, creating a rewarding interaction. The immediate reward generated by this interaction subconsciously creates the impression that throwing away waste is enjoyable. (Unravel Behaviour, 2021) This observation highlights the potency of such a motivator in influencing human behaviour, as a reward is a key factor in proper waste management behaviour. However, it remains uncertain whether this can be a sustainable long-term motivator, as the interaction may eventually become commonplace or even annoying.

Figure 30. The Holle Bolle Gijs bin illustrates how rewarding interactions can effectively encourage individuals to exhibit proper waste management behaviour. Image taken from Pretparken (n.d.).

The Sociable Trash Box robot, illustrated in Figure 31, is another robot that uses engaging interactions to encourage people to dispose of trash in a proper manner. The robot bin roams around, searching for litter on the ground, and captures the attention of nearby individuals to assist in collecting and disposing of the waste in the robot. The researchers stated that individuals who helped the robot felt a sense of satisfaction after the interaction, with children, in particular, being charmed by the robot. Interestingly, despite the robot merely "requesting" people to assist in cleaning up instead of doing the cleaning themselves, people still experienced a rewarding feeling after the interaction and even felt like they were helping the robot. (Aiko, 2012) This sensation of satisfaction motivates behaviour that promotes proper waste disposal, as seen with the Holle Bolle Gijs.

Another bin that encourages proper waste disposal is the Annie Trash, an autonomous bin that moves around at Schiphol, see Figure 32. It is argued that the anthropomorphic aspects of the container contribute to positive feelings during the interaction. The primary objective of the Annie Trash bin is to enhance people's awareness about waste and how they dispose of it. (Service management, 2017)

Figure 31. The Sociable Trash Box is another bin that effectively encourages people to adopt good waste management behaviour, as it "invites" people to help pick up litter, giving them the satisfying feeling that they have helped the robot. Image taken from Aiko (2012).

Figure 32. The Annie Trash bin serves as an example of how incorporating anthropomorphic features in the interaction can foster a more positive user experience and increase people's awareness of waste and their waste disposal behaviour. Image taken from Service management (2017).

Engaging Individuals to Create Waste Awareness

The .BB robot, depicted in Figure 33, serves the purpose of raising awareness among individuals about their waste disposal practices and fostering a shift in their waste management behaviour. To achieve this objective, the robot engages people in its self-learning algorithm that involves the robot taking pictures of litter found on the beach and transmitting them to a mobile app for identification by individuals, as illustrated in Figure 34. This process enables the robot to enhance its litter collection capabilities while simultaneously using gamification techniques to involve people and make them aware of the consequences of litter, a key factor in stimulating good waste management behaviour. Through this interaction, the developers of the .BB robot aspire to stimulate a social dialogue about the implications and consequences of the waste issue and the increasing demand and potential of robots to provide a viable solution. (Project .BB, n.d.)

Figure 33. The .BB robot uses gamification techniques to engage people and increase their awareness of the impact of littering, ultimately encouraging them to adopt proper waste management behaviours. Image taken from Beach Rover – Robohouse (2022)

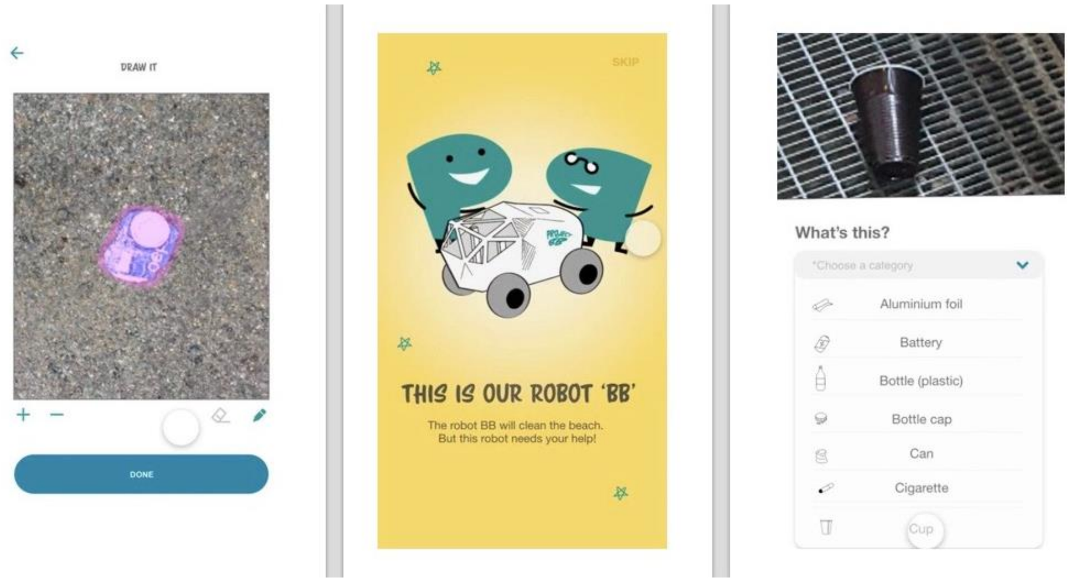


Figure 34. The .BB robot's mobile app is designed to transmit images of found litter to individuals for identification. This process serves to not only improve the robot's algorithm, but also to increase awareness about litter in the environment among individuals. Image taken from Project .BB (n.d.).

Conclusion Key Factors HRI

Currently, the use of robots in public environments is scarce, necessitating the establishment and shaping of human-robot relationships. Given the municipality of Amsterdam's expressed interest in exploring the potential advantages of utilising a robot to address waste management challenges in the city, it is necessary to consider the HRI of the robot, particularly as it is likely to interact with humans when implemented. Therefore, designing this interaction is critical to achieving a positive and successful HRI, promoting robot acceptance, and increasing users' intention to use the robot. Several HRI key factors can be employed, such as the perceived user-friendliness of the robot, which can be improved by enhancing its readability and predictability. The perceived usefulness is another key factor, which depends on the perceived robot's ability to adapt to changing environments and users' needs. Another influencing key factor on the HRI is the subjective social norms, which concern how important individuals in the user's social circle view the robot. These three mentioned key factors belong to a group where an increase leads to higher robot acceptance and intention to use the robot, and therefore a more successful HRI. These factors can be integrated into the design of the robot outlined in this thesis to promote positive interactions with employees of the department Schoon as well as individuals in the urban environment of Amsterdam.

The second cluster of HRI key factors must align with the needs and roles of a specific situation. These factors include the perceived humanness, which is influenced by anthropomorphic features in appearance and behaviour and can help elicit a sense of empathy for the robot. However, an excessively human-like appearance in robots can be perceived as unsettling or disturbing, resulting in a negative HRI. Therefore, a balance must be found when using anthropomorphic aspects in robots. Other factors influencing the HRI that must be congruent with needs and role consistency include perceived social interactivity, which entails that the robot should act and display emotions or human cues in line with social norms, and perceived social presence, which concerns the feeling of being in the presence of another entity. Another HRI key factor that belongs to this group is the sense of safety and comfort when interacting with a robot. This can be enhanced by addressing certain ethical issues, such as defining responsibility, addressing concerns about privacy, asking consent, providing transparency, addressing fear of job replacement, ensuring the user's autonomy and control, and preventing people from being manipulated. Additionally, the perception of pleasantness of the interaction and relationship with the robot can be increased by utilising verbal cues, hand gestures, or personalising aspects. The aforementioned HRI key factors within the second cluster can also be utilised in the design of the robot. It is important to note, however, that these factors must be congruent with the needs and roles in the context of Amsterdam to ensure a positive and successful HRI.

The exploration of HRI in current robots has illustrated the effectiveness of the HRI key factor of pleasantness during interactions to stimulate individuals to adopt proper waste disposal practices. By integrating movements and verbal cues into the interaction, it is possible to create an engaging and rewarding experience that captures attention and actively involves individuals in the cleaning process. This approach stimulates a sense of responsibility towards waste management and can be viewed as a form of "nudging," wherein individuals are subtly encouraged to exhibit desired behaviours. Furthermore, gamification techniques can be employed as a means of influencing people's actions. The .BB robot, for example, uses feedback from the public to train its algorithm, making people subconsciously more aware of waste and influencing their waste disposal behaviour.

Furthermore, the key factor perception of social presence, which indicates the feeling of the presence of another entity, can positively influence correct waste management behaviour in interactions with individuals. This phenomenon was evident in the case of the Sociable Trash Box, where participants reported feeling rewarded by helping the robot. Such responses suggest that participants viewed the robot as a separate entity, allowing them to experience the satisfaction of helping another entity.

Additionally, to effectively promote proper waste disposal behaviour during human-robot interactions, it is crucial to provide individuals with a clear understanding of their expected role to encourage desired actions, such as depositing waste in the robot. Consequently, the key factors of perceived user friendliness and usefulness play a vital role in motivating appropriate waste management behaviour within the interaction. These factors encompass aspects such as readability, predictability, and the ability to adapt to changing user needs and environmental conditions. By enhancing these factors, users can better comprehend their expected roles, contributing to a more effective interaction.

By incorporating these HRI factors into the design of the robot, it has the potential to contribute to a cleaner environment without necessarily performing the physical act of cleaning the environment itself.

The robot exploration also revealed that people have a tendency to anthropomorphise objects around them and form relationships with them, as demonstrated by the Roomba. A recognizable anthropomorphic appearance in a robot can evoke greater empathy, which is important in forming a relationship. Moreover, such appearance can aid in increasing awareness as the robot becomes more recognizable.

Furthermore, the examination revealed that the company of Adlatus, the autonomous building cleaning robot, demonstrated a proactive approach to address cleaners' concerns about possible job replacement, to promote a greater sense of comfort and safety among employees and to encourage greater acceptance of robotic technologies. To ensure successful integration of robots in the department Schoon, a similar approach should be adopted, emphasising the role of these machines as tools rather than as replacements for human workers. This will help clarify how robots can enhance and improve workers' capabilities rather than completely replacing their roles.

4.4 Conclusion Literature Review Developments in Robotics and Key Factors HRI

The objective of this conclusion is to provide an overview of the literature review on developments in robotics and the influential factors shaping HRI. This will serve as a fundamental basis for designing a more feasible robot that can promote a cleaner environment in Amsterdam. Furthermore, new requirements and opportunities are identified for the robot based on the findings of this literature review.

More Robots in our Daily Lives

The technological advancements in machine learning, increasing connectivity, computing power, swarm technology, autonomous driving technology, and the increase in available training data are expected to enhance robots' ability to autonomously navigate complex urban environments in the coming years. This makes the deployment of an autonomous robot in the complex and dynamic city of Amsterdam more feasible. However, while technological advancements have the potential to greatly enhance the capabilities of robots, the fundamental difficulties of coping with unpredictable environments remain challenging. As a result, the extent to which a robot can achieve full autonomy in a busy city like Amsterdam remains uncertain, despite the advancements in technology. For a visual overview of the developments and challenges in robotics, see Figure 27 in Chapter 4.2.

Moreover, the decreasing cost of AI training, hardware components and the increasing capability of machine learning and other technologies are leading to more cost-effective robotic labour in various fields, including manufacturing, transportation and repetitive jobs. The emergence of Robots-as-a-Service has further amplified the feasibility and affordability of robot implementation. Furthermore, AI advancements have expanded robots' capabilities, making automation of high-frequency tasks increasingly feasible and cost-effective. It is predicted that up to 20 million manufacturing jobs may be lost to automation by 2030, which will lead to technology playing a more significant role in our working lives. The adoption of automation is expected to be driven by factors such as Robots-as-a-Service, wage increases, demographic aging, and labour shortages.

Due to the rapid technological developments, integrating robots into department Schoon of the municipality of Amsterdam may be more feasible in the near future. Given the challenges faced by department Schoon, such as heavy workloads and labour shortages, the implementation of robots could provide a valuable solution. By enhancing operational efficiency and increasing capacity without requiring additional manpower, robots can help address the challenges facing the department more effectively.

Shaping Relationships with Robots

To ensure the successful implementation of a robot in the department Schoon, it is critical to establish and shape human-robot relationships with employees and people in the urban environment of Amsterdam. As there are currently few robots in public environments, designing the interaction between humans and robots is necessary to promote acceptance and increase users' intention to use the robot. Several key HRI factors can be used to create a successful HRI, see Table 3 in Chapter 4.3 for an overview of these factors and their application.

The first cluster of HRI factors comprises elements that, when increased, lead to greater robot acceptance and intention to use, thereby contributing to a more successful HRI. These factors include the perceived user-friendliness of the robot, which can be improved by enhancing its readability and predictability. The perceived usefulness is another key factor, which depends on the perceived robot's ability to adapt to changing environments and users' needs.

Another influencing key factor on the HRI is the subjective social norms, which concern how important individuals in the user's social circle view the robot.

The second cluster of HRI key factors must align with the needs and roles of a specific situation. These factors include the perceived humanness, which is influenced by anthropomorphic features in appearance and behaviour and can help elicit a sense of empathy for the robot. However, excessively human-like features in robots can be viewed as unsettling or disturbing, making it essential to strike a balance when incorporating anthropomorphic elements. Additional HRI key factors include perceived social interactivity, which involves the robot's ability to display emotions and human-like behaviour in accordance with social norms, and perceived social presence, which refers to the user's sense of being in the presence of another entity. Sense of safety and comfort is another key factor in the need and role congruency cluster. This can be enhanced by addressing ethical concerns, such as defining responsibility, addressing concerns about privacy, asking consent, providing transparency, addressing fear of job replacement, ensuring the user's autonomy and control, and preventing people from being manipulated. Additionally, the key factor perception of pleasantness of the interaction and relationship with the robot can be increased by utilising verbal cues, hand gestures, or personalising aspects.

In summary, the successful implementation of HRI depends on a careful consideration of the two key clusters of factors. While increasing the first cluster of key factors can lead to higher robot acceptance and intention to use, it is crucial to exercise caution when utilising the second cluster of factors in the design of robots for the Amsterdam environment, as this cluster requires taking into account the unique needs and roles that arise in this context. Therefore, the behaviour of the robot should be adapted to the needs and roles in the context of Amsterdam, to avoid social disruption and to enable the social embedding of the robot.

Rising Ethical Challenges

In the process of implementing a robot, the municipality of Amsterdam must proactively consider the ethical and safety challenges that may arise. It is necessary to ensure the safety and privacy of residents, visitors, and employees. The design of the robot must prioritise respect for human autonomy and control, while determining the responsibility for the actions of the robot. The fear that may arise of job replacement by robots among department Schoon employees must also be addressed to prevent any negative impact on robot acceptance. The municipality can help alleviate these concerns by adopting a collective positive attitude and communicating that the robot can be a tool to support the work of employees and enhance their capabilities, rather than completely replacing their roles. In addition, the department must prioritise safeguarding key employee values that contribute to their job satisfaction during the integration of the robot. The municipality should also address concerns regarding the privacy and safety of residents and visitors with the arrival of a robot and communicate measures to address these issues.

Robots Motivating People to Adopt Proper Waste Behaviour

The municipality of Amsterdam is currently proactively addressing the waste challenges by directing its focus in the waste management towards motivating desired human behaviour. Through the exploration of robots, it has been demonstrated that robots can serve as a potential tool to encourage proper waste disposal behaviour, by engaging people in the interaction and involving them in the cleaning process.

The examination of HRI in the context of waste management has highlighted the effectiveness of key factors such as pleasantness, social presence, perceived user friendliness and usefulness in influencing individuals' waste management behaviour. By integrating movements, verbal cues and gamification techniques, robots can create engaging and rewarding experiences that capture attention and actively involve people in the cleaning process. These approaches act as a form of 'nudging', subtly encouraging desired behaviours and fostering a sense of responsibility towards waste management. As a result, robots can contribute to a cleaner environment without necessarily performing the cleaning themselves.

In order to address waste management challenges on a larger scale, it is important to increase the reach of the robot in Amsterdam, for example through awareness. Anthropomorphic features can be used to increase the awareness and recognisability of the robot. However, it is important to balance the use of anthropomorphic features to avoid causing discomfort or unease and to avoid creating a disturbing robot appearance.

It is important to consider the motivators of littering behaviour when designing the robot to avoid promoting such behaviour. While no evidence supports the claim that a cleaning robot in a private setting can encourage laziness, it remains to be seen what the effects would be of such an autonomous cleaning robot in a public space, where individuals may already feel less accountable. This will be explored in the next chapter using the littering behaviour framework.

Requirements and Opportunities for the Robot

In order to ensure the development of a robotic solution that is adapted to meet the specific needs of Amsterdam, while also taking into account the potential capabilities of robotics in the near future and promoting a positive human-robot interaction, a set of requirements has been formulated based on the conclusions presented in this chapter. These requirements have been compiled and are presented in Table 4, which also provides a rationale for each requirement to highlights its significance. Additionally, a corresponding inventory of potential opportunities arising from technological advancements that can further enhance the development and implementation of a robotic solution in Amsterdam has been compiled, accompanied by an explanation of their importance. This list can be found in Table 5.

To develop an effective robotic solution that meets the specific requirements of Amsterdam and facilitates a cleaner urban environment, a design vision will be established using the insights derived from Chapters 3 and 4. This will be discussed in more detail in the next chapter.

	Requirements	Why
Shaping positive HRI	**Robot's behaviour to avoid social disruption**	Creating a robot to achieve a common goal without disrupting urban/work life for a successful robot implementation in department Schoon and Amsterdam
	Robot's behaviour to enable social embedding	Creating a robot that is intuitive and easy to use, so users can easily interact with it, to enhance robot acceptance and HRI
	Address uncertainty about robots' contribution	To increase the perceived added value of the robot in achieving a common goal, to enhance robot acceptance and HRI
	Align robot's behavior with Amsterdam's context	Align robot behavior with needs and roles in Amsterdam's context to enhance robot acceptance, HRI, and avoid negative effects
	Create a recognisable robot appearance	To facilitate awareness and promote clear expectations for individuals in Amsterdam, enhancing HRI
	Create non-disturbing robot appearance	Minimising uncomfortable feelings in HRI, e.g. by applying considered anthropomorphic features
	Adopt collective positive attitude to robots	To increase robot acceptance and thus HRI, the municipality should adopt a collective positive attitude towards the robot
Feasibility robot development	**Address limitations robot autonomy**	To increase feasibility, limitations on robot autonomy should be considered in the design phase
Ethical challenges municipality	**Define responsibility robot's actions**	To address ethical issues that may arise during robot deployment to improve robot acceptance and HRI
	Address job replacement fears	Concerns about job replacement of department Schoon's employees need to be addressed to enhance robot acceptance and HRI
	Address ethical concerns of robot	Concerns about safety and privacy when deploying robots need to be addressed to enhance robot acceptance and HRI
Ethical challenges robot design	**Ensuring human safety in robots' behaviour**	Ensuring human safety when robots are deployed is needed to improve robot acceptance and HRI
	Ensuring human autonomy in robots' behaviour	Human autonomy and control must always be guaranteed to enhance robot acceptance and HRI

Table 4. In order to ensure the development of a robotic solution adapted to the specific needs of Amsterdam, while taking into account the potential capabilities of robotics in the near future and promoting a positive HRI, a list of requirements is presented.

Opportunities	Why
Increasing cost-effectiveness robotic labour	Robot deployment may be more feasible for Amsterdam municipality
Increasing feasibility robotic labour	Technological advances in robotics in various fields are increasing capabilities and enabling greater autonomy, so robots have significant potential in addressing Amsterdam's waste-related challenges effectively
Adoption of 5G networks	Enables faster connectivity and reduced latency, increasing the speed and efficiency of data transfer

Table 5. The table illustrates a list of potential opportunities for the robot, which can significantly contribute to its successful use and facilitate the development of a more customised and optimal robotic solution.

5

Design Vision

5 Design Vision

In order to be able to generate ideas for a robotic solution that can effectively address Amsterdam's waste management challenges while aligning with the city's needs and requirements, the insights and knowledge obtained from the comprehensive contextual analysis of Amsterdam presented in Chapter 3, the literature review of developments in robot capabilities and the examination of key factors in human-robot interaction, both highlighted in Chapter 4, are used to formulate a design vision.

However, before formulating the design vision, an evaluation will be conducted in Chapter 5.1 to determine whether an autonomous cleaning robot is suitable to promote a cleaner Amsterdam, as the original request was for a cleaning robot. The evaluation will utilise the waste management behavioural framework outlined in Chapter 2 to determine the effect of such a robot on people's relationship with waste. This evaluation is needed to determine a more appropriate design vision for a robot that can effectively improve the cleanliness of Amsterdam.

In addition, as this thesis is focused on a preliminary exploration of the potential of robots to improve the cleanliness of Amsterdam, not all requirements from the previous chapters are equally important in the current design phase. Therefore, an evaluation of the requirements will be conducted in Chapter 5.2 to further guide the design vision in this phase.

This chapter concludes with the design vision of this thesis in Chapter 5.3. This vision is based on the insights gained from previous chapters and provides key details to guide concept development in the following chapters.

5.1 Side Effects of an Autonomous Cleaning Robot

Given the persistent cleanliness challenges in Amsterdam, a plausible robot concept to address these issues would involve the implementation of an autonomous cleaning robot. This hypothetical concept, which we shall refer to as the "ReuzenRoomba" (depicted in Figure 35), could potentially play a significant role in sweeping the streets of Amsterdam and contribute to the overall cleanliness of the city. In order to evaluate the potential viability of the ReuzenRoomba in achieving a cleaner Amsterdam, it is necessary to consider human waste management behaviour, which has been identified as a significant factor contributing to the waste-related challenges faced by Amsterdam. To this end, the waste management behaviour framework presented in Chapter 2 will be utilised to investigate the potential impact of this autonomous cleaning robot on the waste management behaviour of individuals.

Figure 35. The hypothetical concept the "ReuzenRoomba", which is intended to autonomously clean the streets of Amsterdam, will be evaluated based on its influence on the waste management behaviour of individuals to determine the viability of this concept in achieving a cleaner Amsterdam.

Although the initial deployment of the ReuzenRoomba in Amsterdam can lead to cleaner surroundings, thereby positively influencing proper waste management behaviour (as a clean environment is a key factor for motivating proper waste management behaviour), it is important to note that the presence of a cleaning robot in Amsterdam could potentially trigger several key factors of motivating littering behaviour. The key factors that are activated are highlighted in Figure 36 and explained below.

As the robot functions as a cleaning agent, its presence in the urban environment may trigger the key factors "presence of a cleaner" and "belief that a place will be cleaned," which could potentially stimulate littering behaviour. Furthermore, the introduction of an autonomous cleaning robot may inadvertently reinforce a perception among individuals that the responsibility for waste management lies primarily with the robot. This may lead to a reduced sense of personal responsibility for the waste disposal among individuals, which is another significant key factor of littering behaviour. As more individuals start to act in this manner, and others observe such behaviour, littering behaviour is further reinforced as "observing others littering" is another key factor. Consequently, this behaviour may lead to a more polluted environment, which is another key factor. Moreover, if this littering behaviour stimulation continues, it could potentially develop into an undesired "littering habit", which is another key factor that stimulates littering behaviour, further contributing to a more polluted environment.

As a result, the deployment of an autonomous cleaning robot in Amsterdam could lead to a situation where an increasing number of ReuzenRoombas are required to address the increasing levels of pollution. This highlights the importance of avoiding inadvertently stimulating littering behaviour by using a robotic solution to achieve the objective of contributing to a cleaner Amsterdam. It also emphasises the need to consider the motivators of littering behaviour during the design phase of the robot in this thesis.

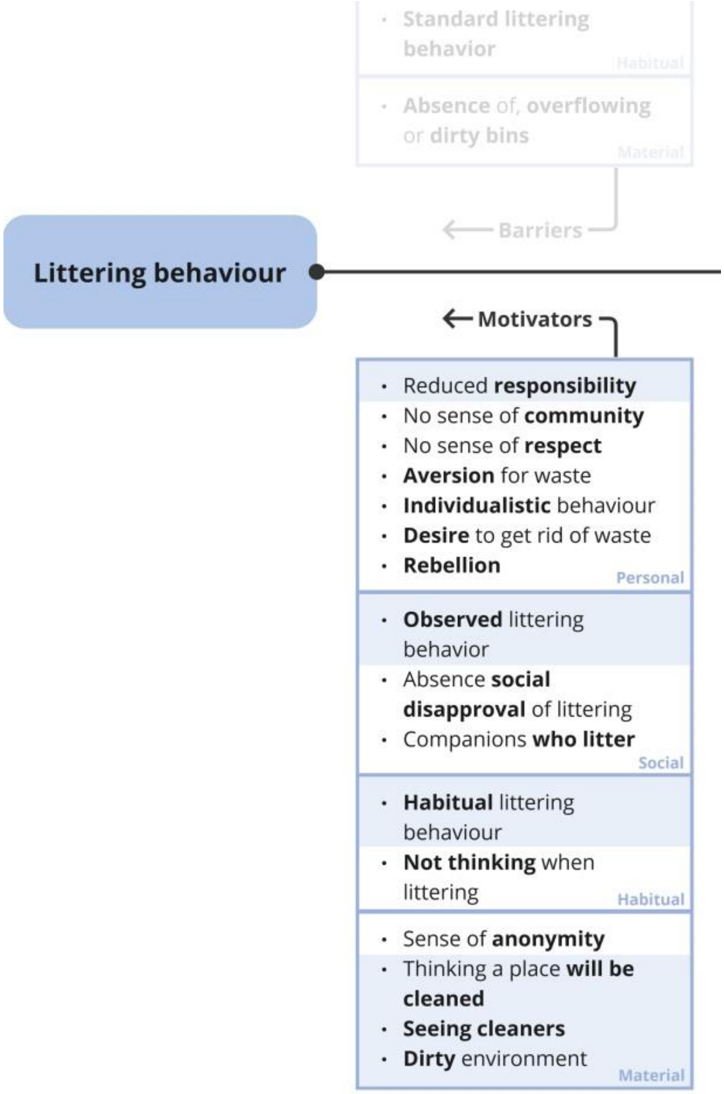


Figure 36. The key factors of the behavioural framework that influence littering behaviour and that are expected to be triggered by the introduction of an autonomous cleaning robot in Amsterdam are highlighted in blue. This suggests that the presence of a cleaning robot is likely to contribute to an increase in littering behaviour, which may lead to a more polluted Amsterdam.

Conclusion Side Effects of an Autonomous Cleaning Robot

In conclusion, while the introduction of an autonomous cleaning robot such as the ReuzenRoomba may result in short-term cleanliness on the streets of Amsterdam, its presence may trigger motivational key factors of littering behaviour, leading to potentially negative long-term effects on individuals' waste management behaviour. In addition, individuals may perceive the cleaning robot as being solely responsible for the management of waste, resulting in a decrease in perceived personal responsibility for waste management and ultimately an increase in littering in Amsterdam, as shown in Figure 37.

This highlights the critical role of the robot's task in shaping people's behaviour and perceptions regarding waste and its management, demonstrating an interdependent relationship between robots, humans, and waste, see Figure 2 for the visual representation of interdependency in Chapter 1. This highlights the need to incorporate additional requirements into the design of the robot in order to avoid unintended consequences, such as an undesirable shift in people's behaviour and attitudes towards waste responsibility, and to enhance its value in achieving a cleaner Amsterdam. These additional requirements, as outlined in Table 6, include avoiding the motivators for littering behaviour in the robot's task (see Figure 38 for these motivators), stimulating proper waste management behaviour in the robot's task, incorporating key factors that promote proper waste management behaviour in the robot's task, and involving people in the act of waste disposal rather than cleaning up after them. By integrating these additional requirements, the robot's added value in contributing to a cleaner Amsterdam can be optimised while minimising undesirable effects on individuals' waste management behaviour.

Figure 37. The introduction of an autonomous cleaning robot may trigger key motivational factors that lead to littering behaviour, with potentially negative long-term effects on individuals' waste management behaviour, as individuals may perceive the robot as solely responsible for waste management, for example, thinking "the robot will clean it up".

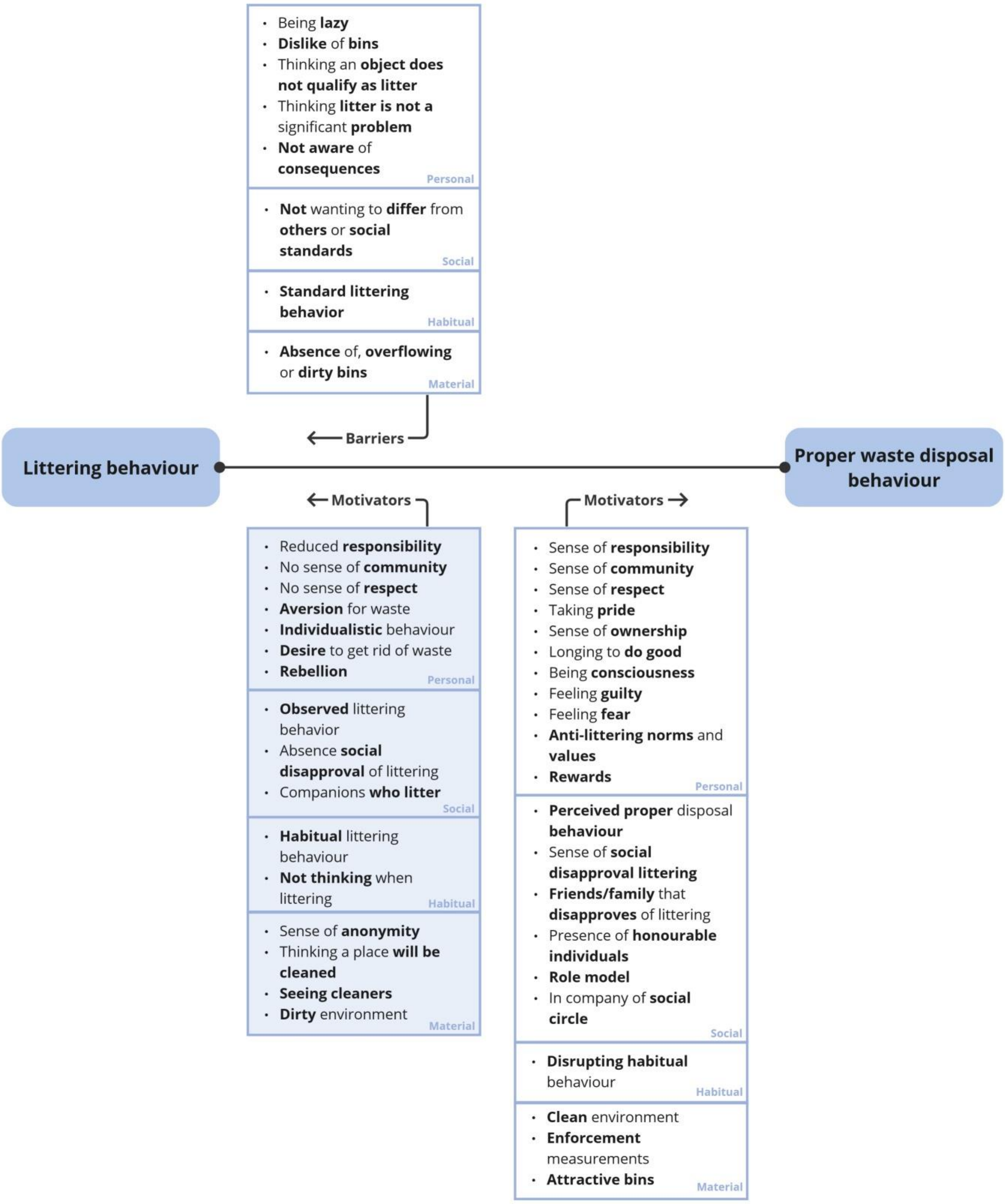


Figure 38. In order to avoid motivating littering behaviour during the deployment of the robot in Amsterdam, which would further increase litter accumulation, it is crucial to avoid triggering the key motivators of littering behaviour, highlighted in blue.

	Requirements	Why
Correct waste disposal behaviour	**Avoid including littering motivators in task**	To prevent stimulation of littering behaviour with the robot's task
	Promote proper waste behaviour in task	Addressing littering behaviour in the robot's task, as it is a major contributor to Amsterdam's waste problems
	Include proper waste behaviour motivators in task	To increase the effectiveness of the robot's added value to a cleaner Amsterdam
	Keep individuals involved in waste disposal	To avoid an increase of littering behaviour, as demonstrated with an autonomous cleaning robot

Table 6. In order to mitigate unintended influences on people's waste management behaviour when a robot is deployed in Amsterdam, it is necessary to include these additional requirements in its design.

5.2 Prioritising Requirements

In order to effectively address Amsterdam's goal of achieving a cleaner city and provide a direction for the design vision, it is crucial to evaluate the compiled requirements from previous chapters. It is important to note that in this initial study, which aims to explore the potential of robots in achieving a cleaner Amsterdam, not all requirements hold equal importance. While some requirements may be vital during the development of an actual robot, they may be of lesser significance in this preliminary phase focused on identifying how a robot can be of value to a cleaner Amsterdam. Therefore, it is important to prioritise and focus on the most critical requirements during this initial phase of the study.

To prioritise these requirements, the MoSCoW Prioritization Categories method will be employed. To determine the respective priorities of the requirements, this method uses four categories, including must-have, should-have, could-have, and won't-have (this time). This method allows a systematic approach to prioritise the requirements based on their level of importance and criticality to the success of this project. (ProductPlan, n.d.)

The first category, "must-have," includes requirements that are indispensable for the robot's minimal core functioning, see Table 7. Failure to meet these requirements will render the product, the robot, in this case, useless, for achieving a cleaner Amsterdam. These requirements include that the robot should promote proper waste management behaviour in its task and that it should keep individuals involved in the waste management process.

The second category, "should-have," refers to requirements that are crucial but not critical to the robot's operation, see Table 8. While the robot can still function without these features, their inclusion can significantly enhance the value. Considering the municipality's potential budget limitations, addressing the cost challenges associated with developing the robot is an extra requirement for this group, as this factor should be taken into account during the design process. Another additional requirement is that the robot's appearance should be in line with the identity of Amsterdam. Discussions with the municipality during Enzo Steehouwer's final presentation revealed that the robot's appearance was a potential challenge, as it was reported that the Mayor of Amsterdam expressed a preference for avoiding carnival-style representations.

However, as the primary objective of this thesis is to explore the potential of robots in achieving a cleaner Amsterdam rather than developing a specific end-product, the third group, referred to as "could-have," has been deemed irrelevant for the scope of this thesis during the categorization process. The prioritization was focused on identifying specific areas of focus for the design phase in this thesis, and no requirements were found to belong to the "could-have" group. As a result, the decision was made to exclude the "could-have" group from further consideration.

Furthermore, certain requirements are considered relatively less significant in the current scope of the design process in this specific timeframe. These requirements will be classified under the "won't-have this time" group, see Table 9. However, they remain crucial for the eventual development and implementation of a robot and are therefore included in the recommendations in Chapter 10.3. Examples of such requirements include determining responsibility for the robot's actions and addressing concerns about job replacement among employees during the robot's development. Additionally, detailed HRI requirements fall under this category, as they require extensive research and development at a later stage.

	Must-have	
	Requirements	Why
Needs Amsterdam	**Achieve cleaning targets**	Achieve cleaning targets will help make Amsterdam more liveable
	Improve waste management efficiency	Growing waste challenges in Amsterdam require more efficient waste management solutions
	Improve waste management sustainability	Amsterdam's sustainability objectives and growing waste challenges require more sustainable waste management solutions
	Promote resident ownership	An objective of the municipality's future vision to address challenges of the city
Correct waste disposal behaviour	**Promote proper waste behaviour in task**	Addressing littering behaviour in the robot's task, as it is a major contributor to Amsterdam's waste problems
	Avoid including littering motivators in task	To prevent stimulation of littering behaviour with the robot's task
	Include proper waste behaviour motivators in task	To increase the effectiveness of the robot's added value to a cleaner Amsterdam
	Keep individuals involved in waste disposal	To avoid an increase of littering behaviour, as demonstrated with an autonomous cleaning robot
	Address littering behaviour	Littering behaviour is a major contributor to waste problems in Amsterdam
Needs department Schoon	**Increase capacity without additional manpower**	Increasing labour shortage, demographic ageing in the Netherlands and workforce shortage in department Schoon, requires increasing capacity without requiring additional workforce
	Safeguard key employee values	Robot implementation can influence employee's job satisfaction, therefore the key values need to be safeguarded
Feasibility robot development	**Address limitations autonomous driving**	To increase feasibility, limitations of autonomous driving technology in a busy Amsterdam should be considered in the design phase
	Address limitations robot autonomy	To increase feasibility, limitations on robot autonomy should be considered in the design phase
Ethical challenges robot design	**Ensure human safety in robots' behaviour**	Ensuring human safety when robots are deployed is needed to improve robot acceptance and HRI

Table 7. An overview of the requirements in the "Must-have" category. Meeting these is important for achieving a cleaner Amsterdam.

	Should-have	
	Requirements	Why
Regulations in Amsterdam	**Emission-free**	Only emission-free vehicles will be allowed in the city center
	Comply with regulation max. walking distance container	To comply with the municipal guideline of a maximum walking distance of 75 metres to a waste container
Correct waste disposal behaviour	**Enable waste disposal at will**	People are not always able to throw away their trash whenever they want, stimulating littering behaviour
	Prevent waste bags on streets	Preventing waste bags from being put on the streets in the first place can reduce waste accumulation and littering behaviour stimulation
	Address littering behaviour tourists	Increase of tourists with own waste behaviour in the city centre may require a different approach because of their short stay
Shaping positive HRI	**Robot's behaviour to avoid social disruption**	Creating a robot to achieve a common goal without disrupting urban/work life for a successful robot implementation in department Schoon and Amsterdam
	Align robot's behavior with Amsterdam's context	Align robot behavior with needs and roles in Amsterdam's context to enhance robot acceptance, HRI, and avoid negative effects
	Create non-disturbing robot appearance	Minimising uncomfortable feelings in HRI, e.g. by applying considered anthropomorphic features
	Create a recognisable robot appearance	To facilitate awareness and promote clear expectations for individuals in Amsterdam, enhancing HRI
Needs Amsterdam	**Address cost challenges robot development**	Considering the municipality's potential budget limitations
	Reduce waste transportation burden	The bridges and quays in the city centre are weak and Amsterdam aims to alleviate the burden
	Align robot appearance with identity Amsterdam	To avoid an undesirable robot appearance for the municipality of Amsterdam
Needs department Schoon	**Reduce task-related physical burden**	Heavy physical tasks may lead to absenteeism and reduce efficiency of department Schoon

Table 8. An overview of the requirements in the "Should-have" category. These are important, but not critical, to achieving a cleaner Amsterdam.

	Won't-have this time	
	Requirements	Why
Ethical challenges municipality	**Define responsibility robot's actions**	To address ethical issues that may arise during robot deployment to improve robot acceptance and HRI
	Address job replacement fears	Concerns about job replacement of department Schoon's employees need to be addressed to enhance robot acceptance and HRI
	Address ethical concerns of robot	Concerns about safety and privacy when deploying robots need to be addressed to enhance robot acceptance and HRI
Shaping positive HRI	**Adopt collective positive attitude to robots**	To increase robot acceptance and thus HRI, the municipality should adopt a collective positive attitude towards the robot
	Robot's behaviour to enable social embedding	Creating a robot that is intuitive and easy to use, so users can easily interact with it, to enhance robot acceptance and HRI
	Address uncertainty about robots' contribution	To increase the perceived added value of the robot in achieving a common goal, to enhance robot acceptance and HRI
Ethical challenges robot design	**Ensure human privacy in robots' behaviour**	Ensuring human safety when robots are deployed is needed to improve robot acceptance and HRI
	Ensure human autonomy in robots' behaviour	Human autonomy and control must always be guaranteed to enhance robot acceptance and HRI

Table 9. An overview of the requirements in the "Won't-have this time" category. These requirements are considered relatively less significant in the current scope of the design process in this specific timeframe.

5.3 Design and Future Vision

To guide the development of design solutions aimed at promoting a cleaner urban environment in Amsterdam, a design vision will be developed. In order to achieve this, the problem statement of this thesis will be formulated, drawing insights from the chapters that analyse the context of Amsterdam, as well as the literature review on the developments in robotics and human-robot interaction. In addition, based on the problem statement, design goals and directions will be established, leading to the formulation of a design vision. Furthermore, a future vision will be outlined, envisioning the long-term benefits of robotic solutions for a cleaner Amsterdam. A visual representation of the problem statement, the design goals, design directions, and design vision can be found in Figure 39.

Problem Statement

The current uncleanliness of Amsterdam is mainly caused by the prevalence of littering behaviour and ineffective waste management practices, which leads to more inefficiency in waste management processes and stimulates littering behaviour among individuals, which further contributes to the uncleanliness of Amsterdam.

Design Goals

Following the problem definition, two design goals have been identified to address the problem statement. As littering behaviour significantly contributes to the growing waste problem in Amsterdam, the first primary design objective is to promote proper waste management behaviour among individuals. The second design goals is to improve the efficiency of the city's waste management system, which is critical given the city's growth and its sustainability goals that necessitate a more effective waste management strategy.

Furthermore, the analysis in this thesis has demonstrated that waste management behaviour can be influenced by how waste management is conducted. People tend to display better waste management behaviour in cleaner environments, and littering behaviour can hinder the efficiency of waste management by increasing waste accumulation, which ultimately reduces efficiency by prolonging the clean-up process for employees. This significant mutual relationship between waste management behaviour and waste management practices is illustrated in Figure 39 with an arrow.

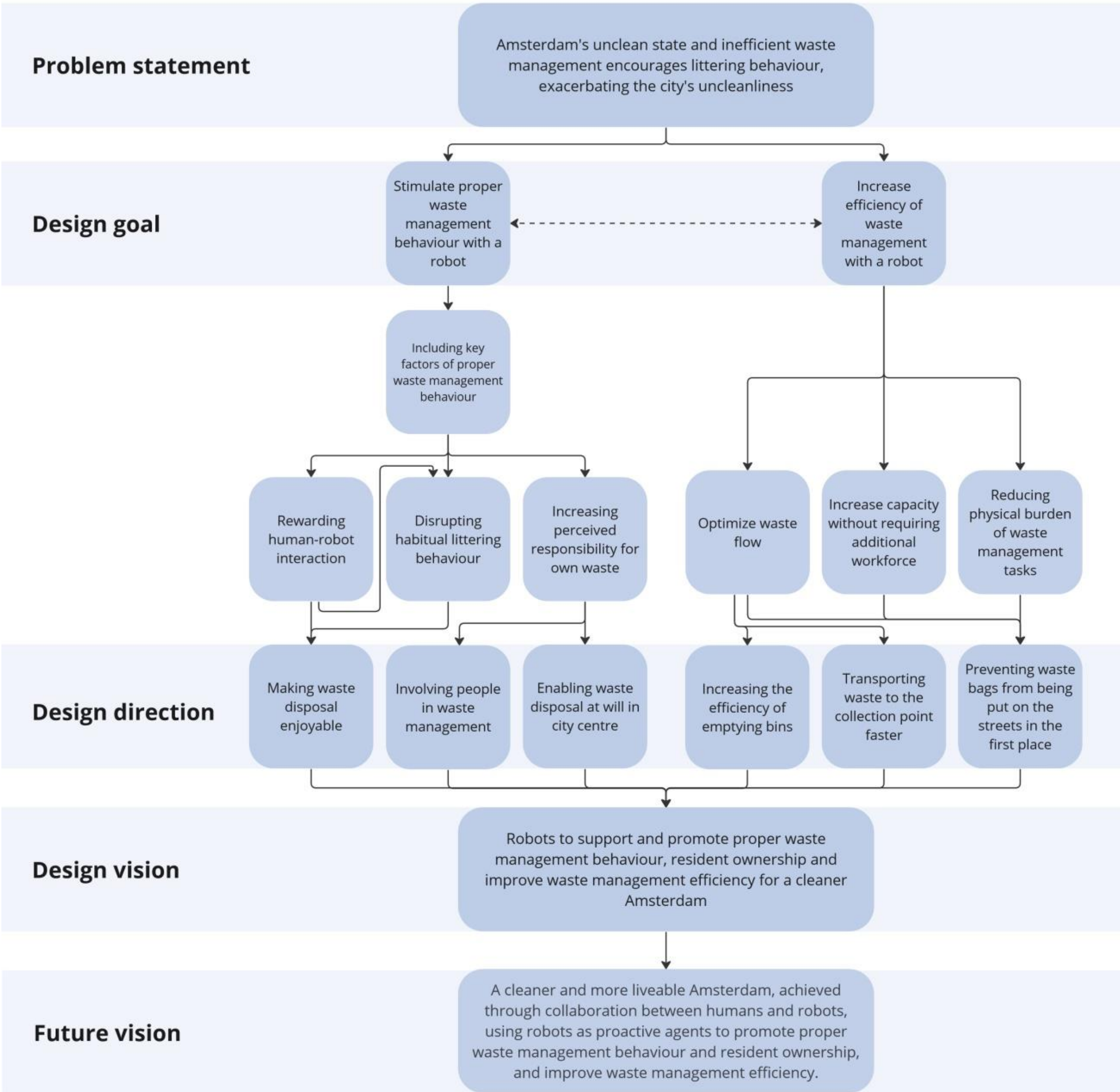


Figure 39. Overview of the problem statement, design objectives, directions, vision and future vision to further guide the development of robotic solutions in this thesis that can contribute to a cleaner Amsterdam. The relationship between waste management behaviour and waste management efficiency is shown with a dotted arrow, e.g. increased waste management efficiency leads to a cleaner environment, which stimulates correct waste management behaviour, which leads to less litter, which leads to increased efficiency by reducing the amount of waste to be cleaned up.

Design Directions

To achieve the design goals, various design directions have been proposed. The first goal, promoting proper waste management, can be accomplished by integrating key factors that motivate such behaviour into the robot's design. While there are several key factors that encourage appropriate waste management practices, not all of them can be easily applied to a robot as many are related to social aspects. However, through the examination of existing robots, it has been demonstrated that the key factors of rewards and disrupting habitual littering behaviour can be utilised to encourage the desired waste management practices. This led to the first design direction of making waste disposal enjoyable or rewarding to stimulate proper waste management practices.

Another critical factor that can be utilised to encourage proper waste management behaviour is the concept of perceived responsibility or ownership for waste. The incorporation of this factor into the design of robots can be achieved by actively involving individuals in the waste management process, thereby ensuring that they are responsible and accountable for their waste. By adopting this approach, robots can serve as a useful tool to facilitate proper waste disposal. Keeping people involved in the act of waste management is crucial in avoiding the perception that the robot is solely responsible for waste disposal. As demonstrated through the exploration of an autonomous cleaning robot, such a perception could stimulate littering behaviour and further increase the uncleanliness of Amsterdam.

In addition to the second design direction of involving individuals in the waste management process, the sense of responsibility can be further enhanced by ensuring that individuals have access to waste disposal facilities at all times. This is particularly important because if individuals are unable to dispose of their waste, they will be more motivated to engage in littering behaviour, as evidenced by cases where waste is left next to full bins or bags are left on the street outside of scheduled times (see Chapter 3.2). In such cases, individuals may see the municipality as responsible for managing the waste rather than themselves, thereby reducing their perceived responsibility. Which is why enabling individuals to dispose of their trash at all times can reduce these situations where littering is encouraged and help maintain a sense of responsibility for one's own waste, reducing the likelihood of littering behaviour.

The second design goal is to enhance the efficiency of waste management in Amsterdam. Improper waste disposal practices, such as leaving waste bags next to overflowing bins and containers, as well as leaving waste on the streets outside of scheduled times, contribute to the accumulation of waste. This results in increased workload and time for the employees of department Schoon, leading to traffic congestion and reduced efficiency. To address this issue, it is important to increase the efficiency of emptying bins and containers to prevent waste accumulation near them. Additionally, it is important to transport waste more quickly to collection sites to prevent overflowing bins and containers, thereby improving the overall waste flow and efficiency of the waste management system.

Furthermore, the department Schoon is currently experiencing labour shortages, which necessitates the hiring of inexperienced temporary workers, further decreasing the efficiency of cleaning teams. This challenge is likely to worsen due to the projected labour shortages and demographic ageing in the Netherlands. Therefore, it is essential to increase capacity without requiring additional workforce, as the current capacity is already insufficient to maintain a clean Amsterdam. Furthermore, labour-intensive tasks such as transferring waste bags from the street to garbage trucks contribute to employee absenteeism due to injuries, which exacerbates the workforce shortages. Therefore, another design direction is to prevent bags from being placed on the street in the first place, thereby increasing capacity and reducing physical burden.

Design Vision

To address the problem statement, the design vision is to achieve a cleaner Amsterdam by developing and deploying a robotic solution in the waste management system that serves as a tool to promote proper waste management behaviour among individuals, increase resident participation, and improve the efficiency of the waste management system in Amsterdam.

This design vision is closely aligned with the overarching vision of the municipality of Amsterdam, which emphasises the collective effort required to keep the city clean: "Together we keep our city clean." (Gemeente Amsterdam, n.d.-d) It recognises the importance of maintaining a sense of shared responsibility among individuals for waste management.

To maintain this collective responsibility, the design vision focuses on supporting and empowering individuals, rather than taking full responsibility for waste management with the deployment of a robot. This approach ensures that the robot acts as a facilitator, complementing the efforts of individuals and reinforcing the idea that a clean Amsterdam is the result of collaborative and collective action. By working together, residents and the robotic solution contribute to a cleaner city, while upholding the municipality's vision of collective responsibility.

Future Vision for the Municipality of Amsterdam

The future vision for Amsterdam includes the integration of robots into the waste management system as part of a proactive approach to achieving a cleaner and more liveable Amsterdam. These robots will serve as a tool to encourage correct waste management behaviour and promote the active involvement of individuals in the waste management process. The use of the robots will optimise the waste flow and improve the overall efficiency of waste management practices. Moreover, the integration of these robots embodies Amsterdam's fundamental principle of promoting a clean city as a shared responsibility of all individuals.

In addition, the use of these robots will increase the labour capacity of the department Schoon without the need for additional human labour, addressing the pressing and growing challenge of labour shortages in the department and in the Netherlands. In addition, the use of these robots will reduce the need for employees to perform physically demanding tasks, thereby reducing the risk of absenteeism due to work-related injuries.

In order to effectively communicate the value of integrating robots into Amsterdam's waste management practices, a range of ideas will be generated and conceptualised to demonstrate how these robots can contribute to a cleaner Amsterdam by promoting proper waste disposal practices among individuals, rather than simply cleaning up after them. These ideas are further developed in the following chapter.

6

Ideation

6 Ideation

In order to effectively communicate the design vision of a robot serving as a tool for promoting a cleaner Amsterdam, instead of solely performing the cleaning function, a range of ideas will be generated. This approach aims to establish a foundation from which concepts can be developed, resulting in more compelling propositions that can effectively convey the value of robotic solutions to the municipality.

The ideation process for developing a valuable robot in Amsterdam involved conducting three brainstorming sessions. The methodology used in these sessions will be described in Chapter 6.1, the insights gained from these sessions will be presented in Chapter 6.2, and the generated ideas are presented in Chapter 6.3. Chapter 6.4 provides an evaluation of the ideas in relation to the requirements of the previous chapter.

6.1 Method

To explore the potential for designing a robot that could meet Amsterdam's needs for achieving a cleaner city, several brainstorming sessions were held, each with its own objectives.

The First Brainstorming Session for Inspiration

In the first session, the goal was to elicit diverse and creative perspectives on developing a valuable robot for the city. Therefore, in addition to the author of this thesis, two people with different educational backgrounds were involved. One participant held a degree in Biomechanical Design from TU Delft, while the other held a degree in Design for Interaction, also from the TU Delft.

In order to encourage the generation of ideas, stimulate inspiration and cover various aspects of the problem, a combination of the "How-Tos" method (van Boeijen et al., 2020) and the brainwriting method was utilised. The brainwriting technique adds to the idea generation as it requires participants to write down their ideas within a given time constraint. (This Is Service Design Doing, 2018) The participants were presented with different "How-To" questions in Miro and given one minute to write down their ideas before moving on to the next question. The questions were structured around themes such as improving cleanliness in Amsterdam, encouraging proper waste disposal, and enhancing the relationship between people and waste. This process was repeated until all questions were answered.

Subsequently, in order to facilitate an in-depth discussion and assess potential changes in ideas, a brief presentation was delivered to provide participants with background information on the anticipated developments in Amsterdam over the next decade, as well as the key factors that influence waste management behaviour. Participants were then asked to respond to the "How-Tos" questions for a second time after the presentation and the session was concluded with a discussion about the results.

The Second Brainstorming Session for Idea Generation
In order to build on the insights gained from the first brainstorming session, a subsequent individual brainstorming session was conducted to further generate ideas. In order to efficiently generate ideas, the method Rapid Ideation Technique was chosen, with a time constraint imposed to encourage one to produce as many concepts as possible. (Wilson, 2022)

The Third Brainstorming Session for Refinement
To further refine and expand on the generated robotic solutions ideas, a third ideation session was conducted. This session was built upon the framework for waste management behaviour factors presented in Chapter 2. The main objective of this session was to explore how these factors could be incorporated into the robot's function. The ideation process was repeated three times, each focusing on a distinct waste issue identified in Amsterdam. In order to broaden the scope of the generated ideas and the robot's functionality, the ideation session also incorporated the use of a preventive-reactive scale. The scale distinguishes between preventive measures, which aim to prevent waste from accumulating on the streets, and reactive measures, which focus on cleaning up waste that has already been discarded.

The findings of these three brainstorm sessions are presented in the following section, while the ideas generated from these sessions are presented in Chapter 6.3.

6.2 Insights Gained from Brainstorm Sessions

During the first brainstorming session, several valuable insights were gained through the discussions. Firstly, a shift in perspective was observed after the brief presentation, with ideas transitioning from a sole focus on cleaning robots to robots that could contribute to a cleaner city without necessarily performing cleaning tasks. This is interesting, as a similar shift is required within the municipality of Amsterdam.

Secondly, the participants emphasised the importance of preserving the existing waste relationship and not compromising it through the implementation of a robot. However, ethical considerations were raised regarding the presence of a talking robot on the streets, as it could feel annoying after a while. The topic of a robot picking up trash by appointment was also discussed, with questions raised about its desirability due to the potential inconvenience of scheduling appointments. Participants highlighted the need to find a balance between convenience and the active involvement of individuals in the waste disposal process.

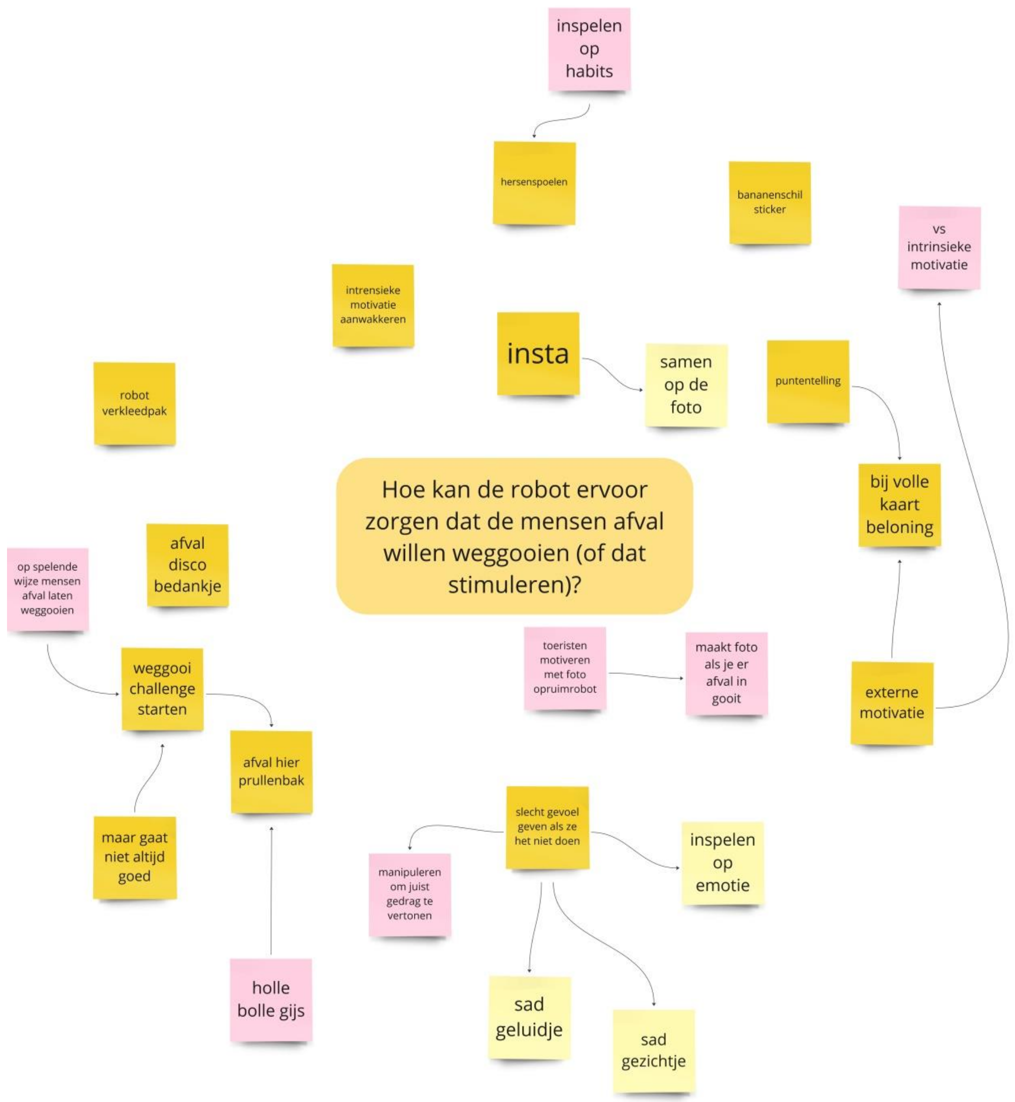


Figure 40. Answers to the question "How can robots make people want to throw away their waste (or encourage them to do so)?" which was used as inspiration.

Lastly, several key considerations for the robot's design were identified, such as the potential incorporation of external or internal motivators, the use of gamification to make waste disposal interactive and enjoyable, leveraging habits to promote effective waste management, raising awareness about the impact of individual actions, and promoting the importance of waste management. Figure 40 showcases the responses to one of the three questions posed during the session, with the other two present in the appendix B.

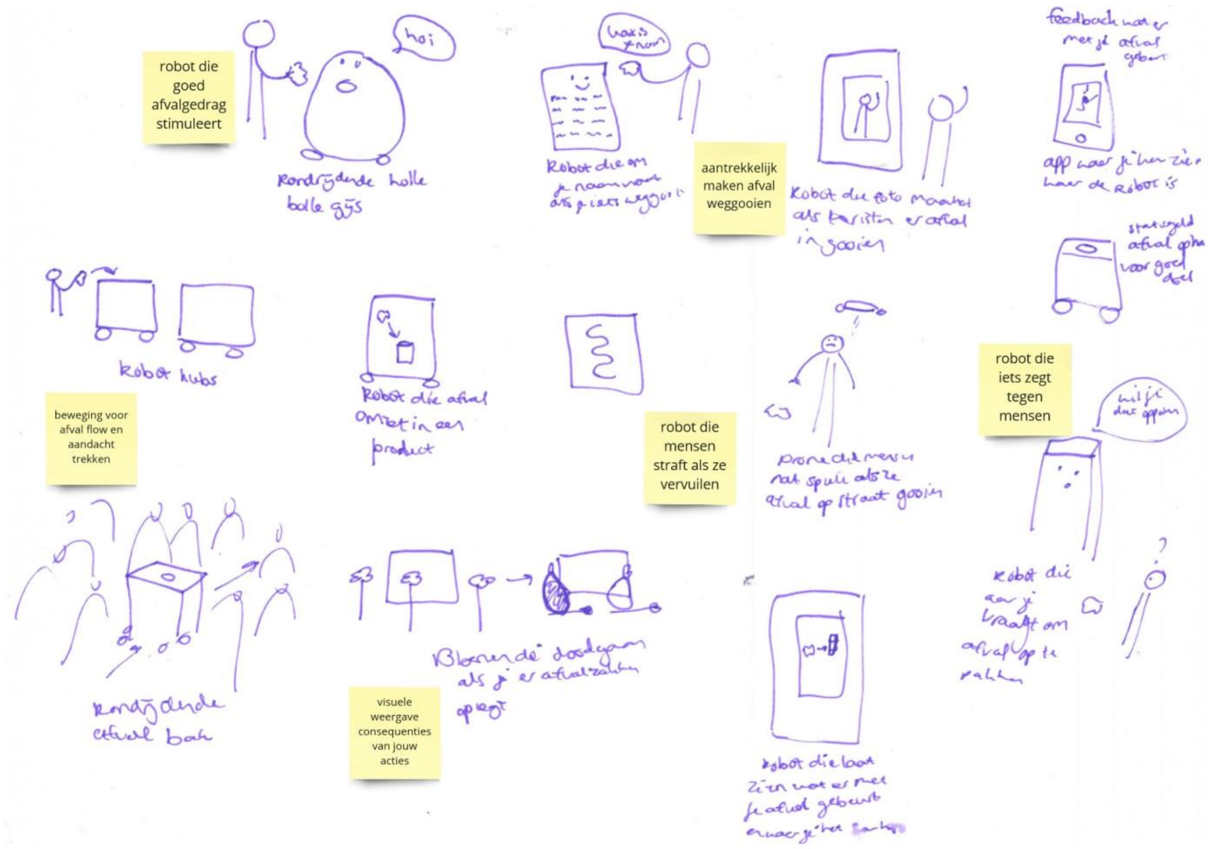


Figure 41. A number of ideas were generated using the Rapid Ideation Technique to explore the potential task of the robot in contributing to a cleaner Amsterdam.

The insights obtained from the second brainstorming session include the potential of using movement not only to optimise the waste flow but also to incentivise desired waste management behaviour by creating an engaging interaction. This suggests that a single task of the robot can be used to optimise the waste flow and influence human behaviour towards proper waste management practices.

Moreover, the second session explored the design of HRI and the motivators that can be employed to stimulate the desired waste management behaviours. Negative motivators, such as punishment or enforcement, were also considered. However, this may create a sense of surveillance and the effectiveness of such enforcement methods has been questioned in previous research. (Lyndhurst, 2013) Consequently, it was concluded that negative motivators are not a suitable approach for designing a stimulating interaction. Figure 41 shows a visual part of the brainstorming session, the rest can be found in Appendix C.

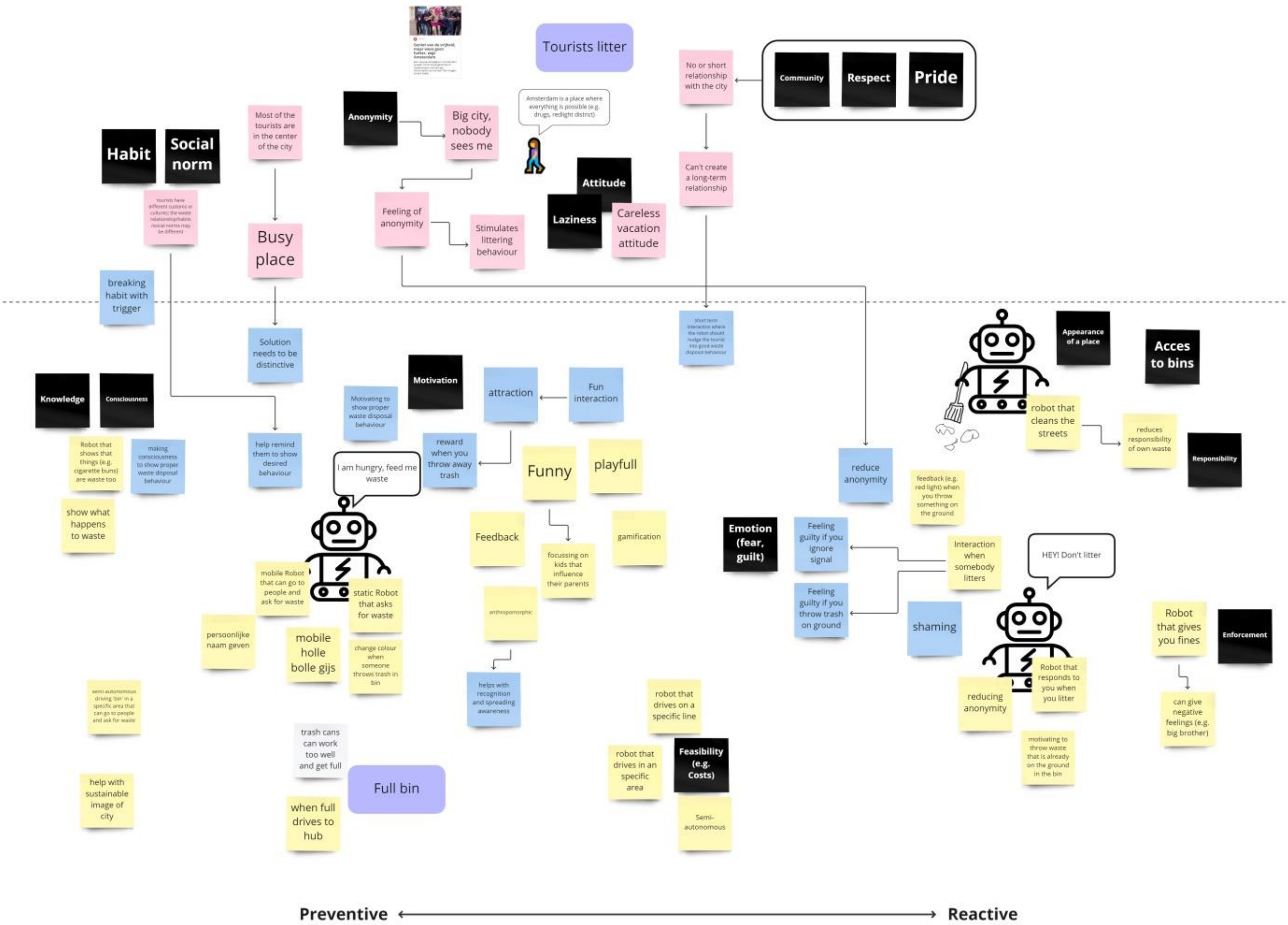


Figure 42. Generating ideas on the waste challenge of littering, particularly by tourists, with factors of waste management behaviour and a preventive-reactive scale, which distinguishes between preventive measures, aimed at preventing litter from accumulating on the streets, and reactive measures, which focus on cleaning up litter.

The insights obtained from the third brainstorming session, which aimed to generate ideas on how to address the waste challenges in Amsterdam using a robot, revealed that addressing these problems effectively would be a challenging task for a single robot. The reason for this is that the first challenge, which is the presence of littered surroundings, is primarily a behavioural problem, while the waste bags placed beside containers and the waste put on the streets are more indicative of inefficient waste management practices. Furthermore, addressing the waste behaviour of tourists, who only have a temporary presence in the city, may present a challenge. However, by proactively anticipating and disrupting undesirable waste behaviour habits and designing the interaction to be engaging or rewarding, this issue could be mitigated. Figure 42 shows a part of the brainstorming session, the rest can be found in Appendix D.

6.3 Brainstorm Sessions Results: Three Generated Ideas

Following the ideation sessions, three ideas were generated, which will be subsequently presented.

Mobile Robot Bin

Given that Amsterdam's city centre is the most contaminated area, which is a significant feature of Amsterdam and the Netherlands, the primary aim of the first idea is to minimise littering behaviour in the centre of Amsterdam. However, the significant presence of tourists in this area, each with different waste relationships and habits, poses a challenge to addressing and changing their waste management behaviour in the short term.

Therefore, the first idea is to introduce a Mobile Robot Bin that can autonomously move around in a limited designated area and interact with individuals who can dispose of their waste in the bin, see Figure 43. The robot bin's interaction with users, such as expressing gratitude, is intended to encourage proper littering behaviour and promote behaviour change by creating a rewarding experience.

The proposed idea aims to address people's littering habits in the urban environment and encourage a change in behaviour by creating a rewarding interaction. It was decided to focus on creating a positive interaction, as it was concluded during the brainstorming session that negative motivators were not an appropriate approach for designing an interaction that stimulates proper waste management behaviour. The incorporation of anthropomorphic features into the robot's design aims to stimulate recognition, increase public awareness and elicit empathy when interacting with individuals, ultimately resulting in a more positive HRI. (Tan, Sun & Šabanović, 2016)

Figure 43. The idea of the Mobile Robot Bin, which aims to create a rewarding interaction to motivate proper waste disposal behaviour in individuals.

Self-Driving Robot Container

The second proposed idea, the Self-Driving Robot Container, see Figure 44, aims to address the problem of waste bags being placed next to containers, which often happens when containers are perceived to be full or at maximum capacity. Not only does improper waste disposal lead to an unclean environment, it also hinders the efficiency of waste collection practices. This is because waste collectors have to remove the bags before they can proceed with emptying the containers.

These containers operate autonomously and are designed to move to a waste collection point when they reach their maximum capacity. Equipped with an automatic signalling system, these containers communicate with a central facility where other containers are located when they reach their limit. This communication allows an empty container to be sent to replace a full one. Once the full container has been replaced, it goes to the collection point for disposal and returns to the central facility until it is needed again.

The proposed idea aims to provide people with constant access to waste disposal facilities while avoiding the problem of overflowing bins, ultimately resulting in a cleaner environment, more efficient waste collection processes through streamlined waste flow and reduced motivation for littering behaviour.

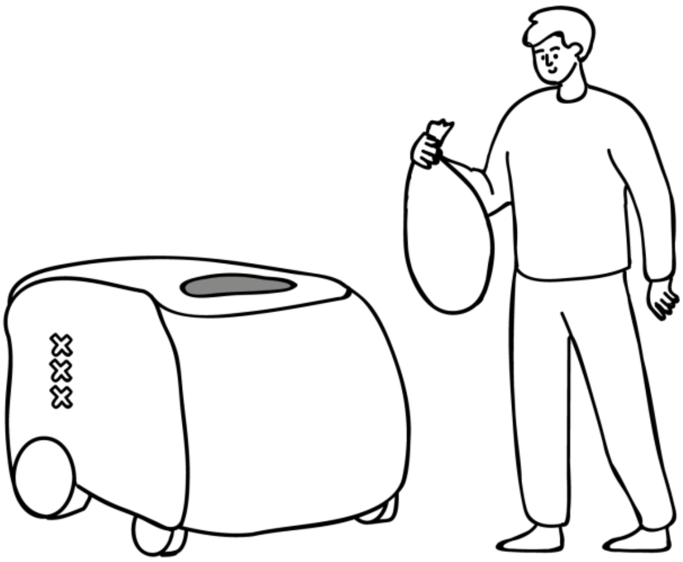


Figure 44. The idea of the Self-Driving Robot Container, which aims to solve the problem of waste bags being left next to containers by autonomously transporting waste to a collection point when they reach their maximum capacity.

Garbage Collection Robot

The city centre of Amsterdam poses waste management challenges due to space constraints for underground containers and structural limitations of weak bridges and quays. As a result, the municipality is investigating alternative methods of waste transport that do not rely on heavy trucks. In addition, the existing policy of placing garbage bags on the street, as described in Chapter 3.2, leads to the accumulation of waste and other related problems. In addition, the manual waste collection process carried out by department Schoon places significant physical strain on employees, resulting in increased absenteeism and reduced waste management efficiency.

To address these challenges, the proposed idea is to introduce a self-driving Garbage Collection Robot, see Figure 45. Individuals will be able to make appointments to dispose of their waste in the robot, building on the success of previous trials of electric bicycles for waste collection by appointment in Amsterdam.

The Garbage Collection Robot allows individuals to dispose of their waste at a time of their choosing, thereby empowering them to exercise greater control over their waste disposal schedules. This approach emphasises individual responsibility for waste management, as individuals remain responsible for their waste until it is handed over to the robot. As a result, the prevalence of improperly disposed bags on the street is likely to be reduced, and the physical strain on waste collectors is reduced by eliminating the need to manually handle bags during collection, potentially reducing the risk of absenteeism due to injury. It also eliminates the need for heavy waste collection vehicles to drive over bridges and quays, reducing congestion in these areas.

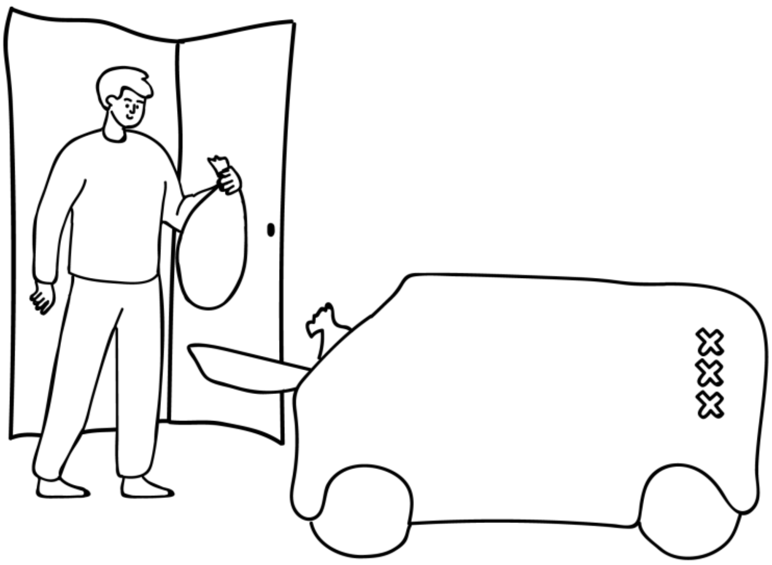


Figure 45. The idea of the Garbage Collection Robot, which aims to solve the problems associated with the policy of placing waste bags on the street in the centre, by autonomously collecting waste in the centre when people make an appointment with the robot.

6.4 Evaluation of the Three Ideas with Requirements

An evaluation will be conducted to assess the potential success of the three proposed ideas. The compiled and prioritised requirements outlined in Chapter 5.2 will be used to determine their potential value in promoting a cleaner environment in Amsterdam. Table 10 and 11 illustrate the comparison of the robot ideas with the requirements, making it easier to check their compliance with the defined criteria.

For requirements that are not fully met by the proposed ideas, appropriate solutions will be proposed to fill the gaps and increase their effectiveness, so that the robot concepts better meet the requirements and contribute to a cleaner Amsterdam.

	Must- have requirements	Mobile Robot Bin	Self-Driving Robot Container	Garbage Collection Robot
Needs Amsterdam	**Achieve cleaning targets**	+	+	+
	Improve waste management efficiency	+	+	+
	Improve waste management sustainability	+	+	-
	Promote resident ownership	+	+	+
Correct waste disposal behaviour	**Promote proper waste behaviour in task**	+	+	+
	Avoid including littering motivators in task	+	+	+
	Include proper waste behaviour motivators in task	+	+	+
	Keep individuals involved in waste disposal	+	+	+
	Address littering behaviour	+	+	+
Needs department Schoon	**Increase capacity without additional manpower**	+	+	+
	Safeguard key employee values	+	+	+
Feasibility robot development	**Address limitations autonomous driving**	+	-	-
	Address limitations robot autonomy	-	-	-
Ethical challenges robot design	**Ensure human safety in robots' behaviour**	+/-	+/-	+/-

Table 10. When comparing the proposed ideas with the "Must-have" requirements, it is evident that some of these requirements are not adequately met, as indicated by the red boxes. In addition, requirements marked with a plus/minus symbol indicate that attention is required to address and improve their fulfilment within the ideas.

	Should-have requirements	Mobile Robot Bin	Self-Driving Robot Container	Garbage Collection Robot
Regulations in Amsterdam	**Emission-free**	+	+	+
	Comply with regulation max. walking distance container		+	+
Correct waste disposal behaviour	**Enable waste disposal at will**	+	+	+
	Prevent waste bags on streets		+	+
	Address littering behaviour tourists	+		
Shaping positive HRI	**Robot's behaviour to avoid social disruption**	+	+	+
	Align robot's behavior with Amsterdam's context	+	+	+
	Create non-disturbing robot appearance	+	+	+
	Create a recognisable robot appearance	+	+	+
Needs Amsterdam	**Address cost challenges robot (development)**	+/-	-	-
	Reduce waste transportation burden centre			+
	Align robot appearance with identity Amsterdam	-	-	-
Needs department Schoon	**Reduce task-related physical burden**		+	+

Table 11. When comparing the proposed ideas with the "Should-have" requirements, it is evident that some of these requirements are not adequately met, as indicated by the red boxes.

Evaluation Mobile Robot Bin

The idea of the Mobile Robot Bin is to act as a tool to promote responsible waste management practices among individuals, thereby contributing to a cleaner environment in Amsterdam. The robot meets most of the requirements. In order to overcome the challenges related to autonomy, the operation of the robot will be limited to certain areas, such as squares. In addition, a low speed limit will be applied, which not only increases the possibility of achieving autonomy, but also improves safety by minimising the likelihood and severity of collisions.

Discussions with the municipality revealed that the robot's appearance could be a potential challenge, as it needs to avoid carnival-style representations. Therefore, it is proposed that Amsterdam-based artists collaborate on the robot's appearance to ensure that it is in line with the city's aesthetics and identity. In addition, the robot's personality and appearance could be tailored to the area in which it operates. For example, in the upscale Kalverstraat neighbourhood, the robot's personality could be designed to reflect a more butler-like character, while a different approach could be taken when operating in Dam Square. The appearance of the Mobile Robot Bin needs to be carefully considered to fit in with the identity of Amsterdam, and feedback from the municipality will be sought in the feedback session, see Chapter 8.2.

In terms of cost challenges, reducing the number of components used in the robot can lead to a more cost-effective solution. It is therefore important to consider the number of components required to interact with human users. Careful evaluation of the need for features such as speech recognition technology is essential to ensure cost effectiveness. It may not be necessary to include conversational capabilities, as simple interaction between the two parties may be sufficient to encourage proper waste disposal practices. Such considerations can potentially lead to reduced development costs.

Evaluation Self-Driving Robot Container

The Self-Driving Robot Container meets almost all of the must-have requirements, but it may face feasibility issues in achieving autonomy due to uncertainties surrounding the development of autonomous driving technology and the technical difficulties associated with navigating a dynamic urban environment like Amsterdam. To mitigate these concerns, several measures can be taken. Several measures can be taken to mitigate these concerns. For example, the robot's exposure to busy traffic can be reduced by using cycle lanes. In addition, the establishment of local waste collection points where robots can dispose of their waste and recharge, in line with Amsterdam's objective of creating hubs, can minimise the distance travelled, thereby increasing the likelihood of achieving autonomy in the robot.

However, the proposal for a Self-Driving Robot Container may prove to be cost-intensive due to the need for new infrastructure in areas where pre-existing underground containers are located. Establishing new robot infrastructure and removing the old containers could lead to significant costs that need to be taken into account. A solution to this is proposed in the conclusion.

Furthermore, the robot's appearance must be taken into account to ensure that it conforms to Amsterdam's identity and fits into the urban landscape.

Evaluation Garbage Collection Robot

The proposed Garbage Collection Robot, which shares similarities with the Self-Driving Robot Container, may face comparable challenges. The feasibility of this concept remains uncertain due to the constant movement of the robot, as individuals can make appointments for the robot to come to their doorstep to collect their waste, and the current uncertainty surrounding the development of autonomous vehicle technology. The constant movement of the robot could result in high energy consumption, reducing the sustainability of this proposed additional waste management practice, and cost concerns.

In addition, the proposed approach of scheduling appointments with the robot may represent a significant change from the current practice of regular waste collection, which may cause resistance from residents. However, this robot idea could bring significant benefits to both residents and the municipality by providing a solution to the problems caused by waste bags being placed on the street. The robot would prevent waste being left on the streets and reduce the problems associated with this.

The robot's appearance must also be taken into account and evaluated with the stakeholders to ensure that it fits in with Amsterdam's identity and the urban landscape.

Conclusion Evaluation of the Three Ideas

In conclusion, the proposed Mobile Robot Bin has the potential to promote responsible waste management practices and contribute to a cleaner environment in Amsterdam. However, its appearance needs to be in line with the city's identity and should be evaluated with the municipality. In addition, to address the challenges of autonomy, the Mobile Robot Bin's operation will be limited to certain areas, such as squares. In addition, a low speed limit will be applied, also to improve safety.

In addition, the feasibility of the Self-Driving Robot Container and the Garbage Collection Robot remains uncertain due to the challenges associated with autonomous driving technology. In particular, the Garbage Collection Robot presents logistical challenges due to its constant movement, resulting in potentially high energy consumption and potential resistance from residents who may need to schedule waste collection appointments. In addition, the implementation of the Self-Driving Robot Container could involve significant costs, as it would require the installation of new infrastructure in areas where underground containers already exist.

To overcome these challenges, the integration of both concepts into one robotic solution, the Mobile Robot Container, is proposed. This robotic solution would be deployed in the centre of Amsterdam, allowing residents to dispose of their waste at will, and addressing the problem associated with placing garbage bags on the street. When the robot reaches its capacity, it would autonomously return to its hub via bicycle lanes and a replacement robot container would take its place. This approach takes advantage of both ideas to create an effective waste management solution while minimising cost and potential disruption to existing waste management infrastructure.

The following chapter provides a detailed explanation of both the Mobile Robot Bin and Mobile Robot Container concepts.

7
Two Robot Concepts for a Cleaner Amsterdam

7 Two Robot Concepts for a Cleaner Amsterdam

For Amsterdam to become a cleaner city, it is essential that individuals remain involved in the waste management process, rather than relying on robots to take care of it. In order to communicate this message in a more concrete and effective way, the ideas of the previous chapter are transformed into concepts. In this chapter the two concepts are presented. The Mobile Robot Bin is introduced in Chapter 7.1 and the Mobile Robot Container is described in Chapter 7.2. A conclusion is provided that gives an overview of the two concepts (in combination with the ReuzenRoomba of Chapter 5.1) to emphasise the importance of involving people in the waste management process.

7.1 The Mobile Robot Bin

In the following sections, the Mobile Robot Bin (see Figure 46) concept is explained in more detail in order to provide a comprehensive understanding of the concept. In order to facilitate effective communication and enhance clarity, a storyboard method has been used. This method visualises and outlines the sequential steps involved in the Mobile Robot Bin process, providing a more visual representation of its functionality and operation. (Andriole, 1989)

In order to provide a more comprehensive understanding of the Mobile Robot Bin, this chapter also discusses the rationale behind its appearance. In addition, to illustrate the interrelated processes that underpin the Mobile Robot Bin concept, a Service Blueprint has been developed, as this approach is widely used to map the relationships between different components in a service. (Gibbons, 2017) This blueprint will be discussed in more detail later. The benefits of the robot in addressing different challenges are described as well.

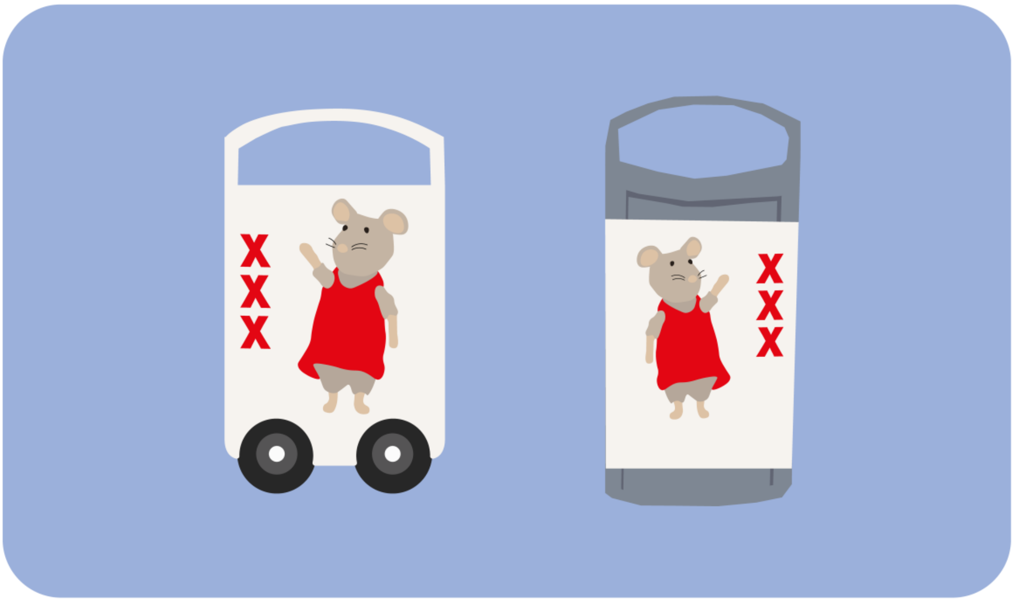


Figure 46. The Mobile Robot Bin, left, and its appearance translated to regular bins, right. The reason for the appearance translation is explained below.

Storyboard Mobile Robot Bin

The Mobile Robot Bin is an autonomous self-driving waste bin that aims to reduce littering behaviour of individuals in the central district of Amsterdam, as this is the most littered area, by disrupting habits of littering behaviour and encouraging responsible waste behaviour through incentives and rewarding interactions. See Figure 47 for the storyboard of the concept.

The first stage, referred to as Interaction, aims to promote proper waste disposal behaviour among individuals in public spaces through the human-robot interaction. The robot bin will be designed to interact with individuals who deposit waste into the robot, expressing gratitude and creating a rewarding experience that incentivises the desired behaviour. When the robot bin reaches capacity, it will direct individuals to an available empty bin, ensuring continuous operation as an agent of responsible waste disposal practices and preventing it from becoming inoperable when full. Real-time monitoring of waste levels in the robot allows for an optimised emptying schedule, thereby enhancing the efficiency of waste management. Equipped with sensors and cameras, the Mobile Robot Bin is intended to operate autonomously, avoiding obstacles and pedestrians to ensure safe operation in public spaces. To address the challenges associated with autonomous driving technology, the proposed robot will operate within a designated area in the centre of Amsterdam at a maximum speed of 6 km/h, in accordance with pavement regulations. (Ministerie van Algemene Zaken & Rijksoverheid, n.d.) Limiting its operation to a small designated area increases the feasibility of achieving autonomy within a decade, while addressing safety concerns associated with collisions by operating at a reduced speed.

The aim of the second stage, called Emptying, is to increase the efficiency of the waste management process by optimising the process of emptying the robot bins. To achieve this, employees from the department Schoon can summon the robot bins by sending a signal before arriving at the designated meeting point. The Mobile Robot Bins then travel autonomously from various locations to the central meeting point, line up and wait for the employee's arrival. This approach allows for an efficient and easy emptying process. Once the bags have been replaced in the Robot Bins, they autonomously return to their designated locations. This emptying process is significantly more efficient than the traditional approach of driving to each bin individually and emptying them one by one.

The third stage, referred to as Processing, involves transporting the collected waste to a designated collection site for further processing and recycling.

Mobile Robot Bin

1 Interaction
The robot bins draw attention and express gratitude upon the disposal of trash. Even when full, they continue to act as proactive agents by directing individuals to other bins, reinforcing proper waste disposal behaviour.

2 Emptying
Upon the arrival of a department Schoon employee, the robot bins automatically assemble at the meeting place and arrange themselves for streamlined and efficient emptying.

3 Processing
The waste is transported to a collection site for further processing and recycling.

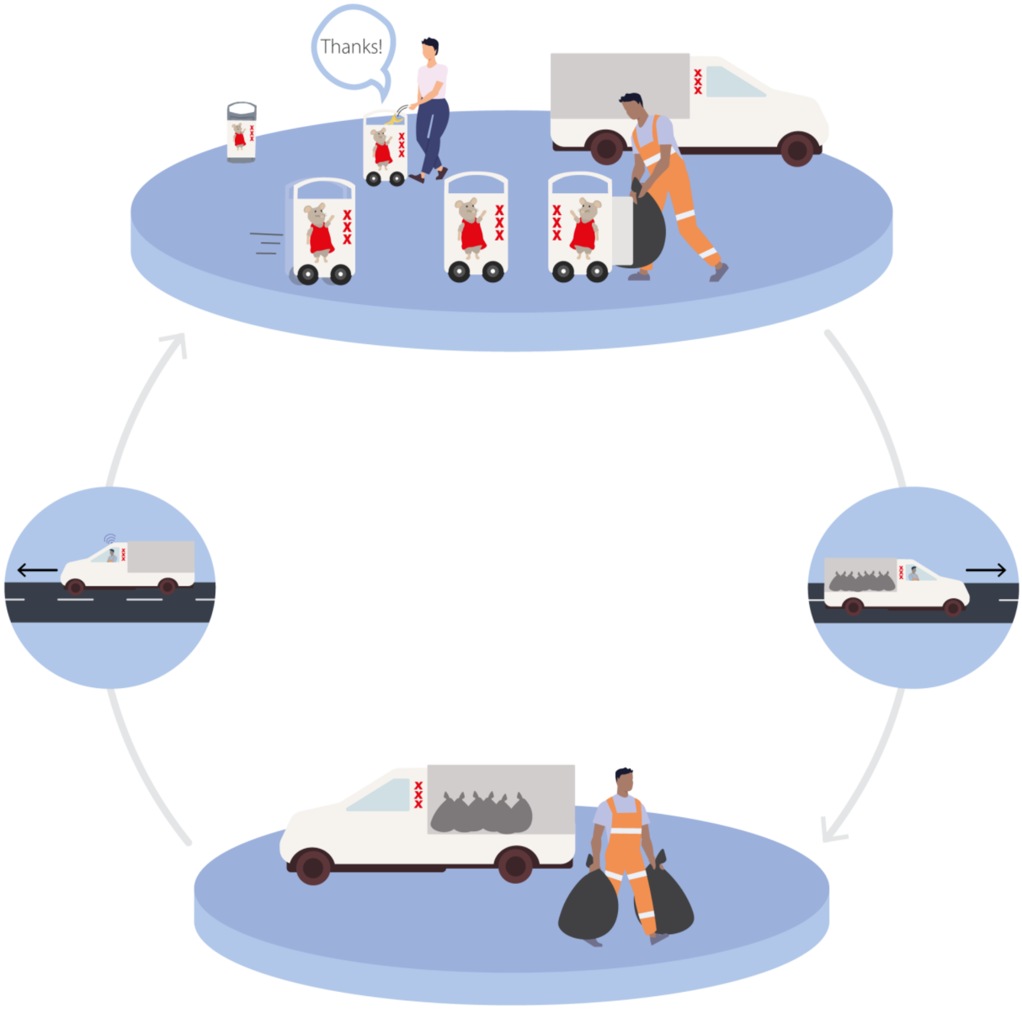


Figure 47. This storyboard provides a visual representation of the Mobile Robot Bin concept, showing its different stages to give a clearer understanding of the concept.

Appearance of the Mobile Robot Bin

Consideration has been given to the design of the Mobile Robot Bin to ensure that it is effectively recognised as a waste bin, thereby encouraging people to use it for waste disposal purposes. The design of the robot was intentionally modelled on the typical shape of litter bins found in Amsterdam to increase its recognisability.

Moreover, to maximise the impact of the design of the robot in a cost-effective manner, the potential transfer of its appearance to stationary trash bins can also be considered. Therefore, the appearance of the robot and stationary trash bins should not differ significantly to facilitate the transfer of the design and increase its overall impact.

Another challenge to consider is the avoidance of a carnival-like appearance, as it does not align with the desired image of the municipality of Amsterdam. To ensure a more suitable aesthetic, the appearance and identity of the robot will be developed in partnership with local artists, with the aim of enhancing the Amsterdam feel and promoting public awareness through a recognisable appearance that fits in with the city's identity.

In addition, community members living in the areas where the robots will be deployed will be actively involved in the design process. This involvement serves multiple purposes, including fostering a sense of ownership among residents and preparing them for the arrival of the robots. Residents will be presented with several design options and given the opportunity to select their preferred choice, thereby contributing to the customisation of the robot's appearance. The current design concept is inspired by the artwork of Karina Schaapman, a renowned Amsterdam artist known for 'het Muizenhuis' (the Mouse House).

Service Blueprint Mobile Robot Bin

In order to better understand the underlying processes and interrelationships that enable the steps outlined in the previous storyboard to be properly executed, a Service Blueprint of the Mobile Robot Bin is developed, as shown in Figure 48.

The Service Blueprint comprises multiple layers to visualise the involved processes in the Mobile Robot Bin. (Gibbons, 2017) The Individual actions layer depicts the various steps undertaken by an individual when disposing of their trash in a public space where the robot bin is located. The Front-stage robot actions layer illustrates the visible actions of the robot when interacting with the individual.

In the Service Blueprint methodology, the backstage actions layer is separated from the previous layers by a line of visibility. This separation indicates activities that are essential to the operation of the service, but invisible to the individuals receiving the service. (Gibbons, 2017) In the case of the Mobile Robot Bin, however, these backstage actions performed by the robots are visible to people in the urban environment, such as their gathering at a designated location. Nevertheless, in order to maintain a clear and comprehensive overview in the visual, it was decided that maintaining the line of visibility would serve to distinguish between actions that involve individuals and actions that do not directly involve the participation of individuals but contribute to the overall service delivery.

The Back-stage robot actions layer includes the 'invisible' actions performed by the robot bin to ensure the proper functioning of the service. The Back-stage employee actions layer describes the specific actions performed by an employee to facilitate and support the effective functioning of the Robot Bin service.

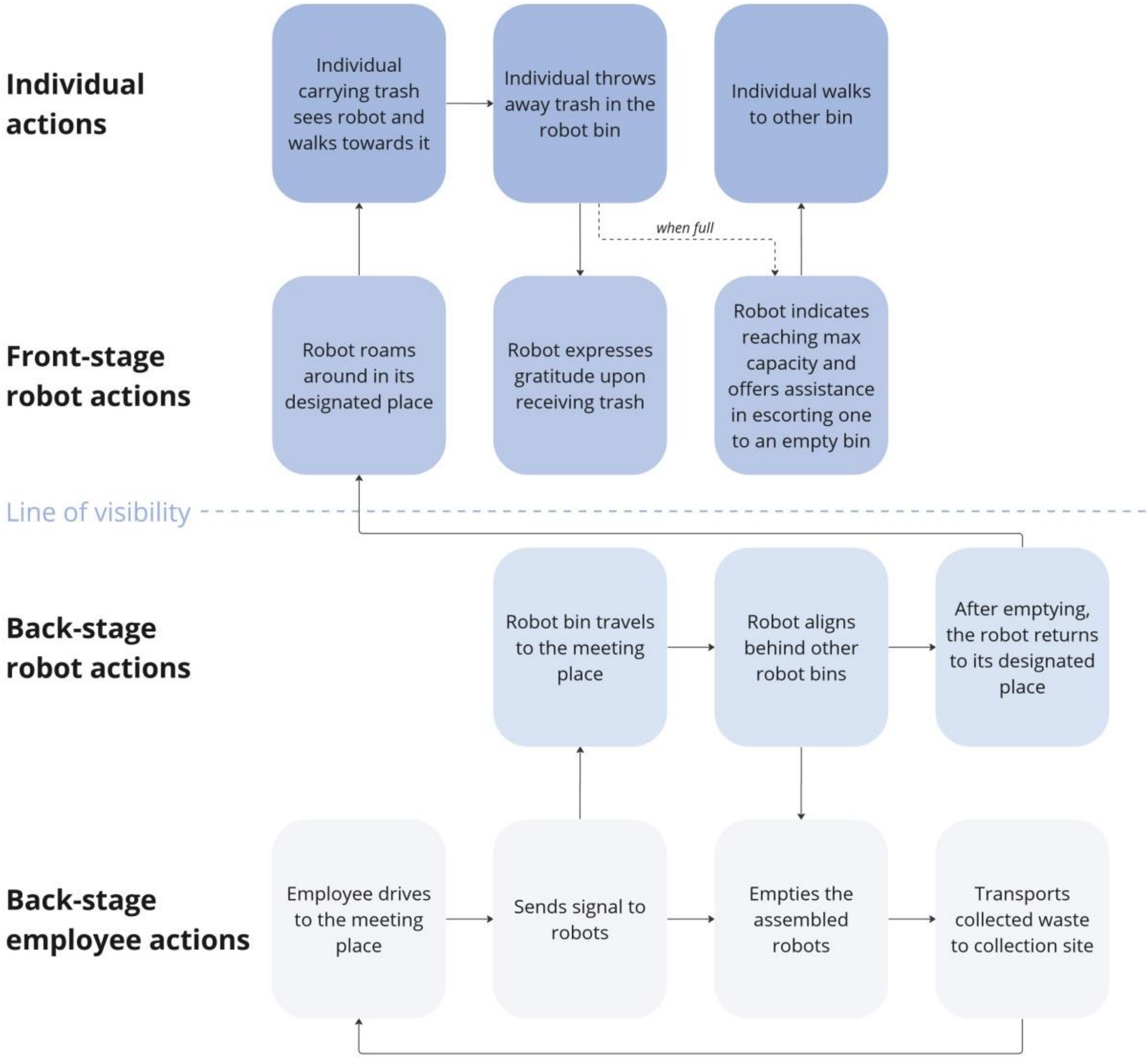


Figure 48. The Service Blueprint provides a visual representation of the Mobile Robot Bin concept, showing the interconnected processes. To facilitate seamless coordination and communication between employees and the Mobile Robot Bins, the implementation of a communication infrastructure is essential. This infrastructure enables employees to initiate a signal that prompts the robots to assemble at the designated collection point, ensuring effective interaction and collaboration.

Benefits of the Mobile Robot Bin

The proposed Mobile Robot Bin offers several benefits, including addressing established littering habits and promoting proper waste disposal behaviour by rewarding interactions. Furthermore, the robot encourages personal responsibility for one's own waste, as people are required to dispose of their own waste instead of relying on the robot to perform that task. In addition, the robot is aimed at addressing the major littering issue in the centre of Amsterdam, which is a crucial representation of the city and the Netherlands.

The robot's distinctive and unique appearance, designed by Amsterdam artists to match the city's identity, is intended to raise public awareness, and the involvement of residents in the design process is intended to foster a sense of ownership.

The movements of the Mobile Robot Bin serve several functions, including attracting attention to encourage proper waste management behaviour and enhancing the efficiency of waste collection by facilitating a streamlined waste collection. By facilitating efficient bin emptying, the robot improves efficiency and convenience for the department Schoon employees. Additionally, the robot allows for monitoring of its waste level, enabling a flexible pickup schedule that optimises the emptying of the robots based on predictive scheduling.

7.2 The Mobile Robot Container

The following sections aim to provide an explanation of the Mobile Robot Container concept. The robot can be seen in Figure 49. To gain a better understanding of how the Mobile Robot Container is utilised in the context over time, the storyboard method is employed, which outlines the various steps involved in the concept. (Andriole, 1989)

Furthermore, to facilitate a more comprehensive understanding of the processes and interrelationships that underpin the Mobile Robot Container concept, a Service Blueprint has been developed. (Gibbons, 2017). This blueprint will be described in detail later. Additionally, the appearance and benefits of the proposed concept will also be outlined.

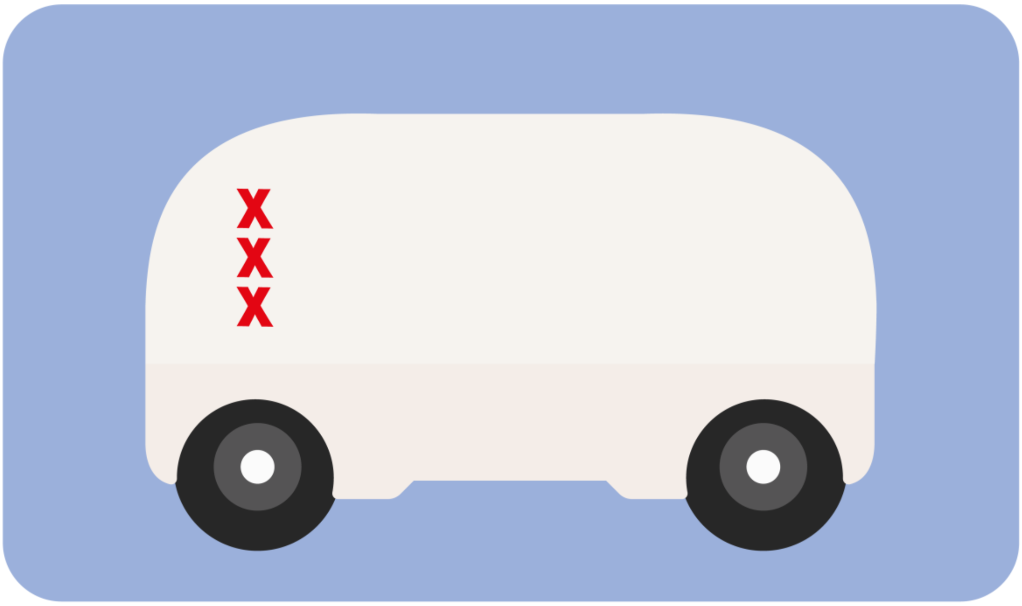


Figure 49. The Mobile Robot Container, left, and its appearance translated to regular bins, right. The reason for the appearance translation is explained below.

Storyboard Mobile Robot Container

The primary objective of the Mobile Robot Container is to enhance the cleanliness of the streets of Amsterdam in the centre, by introducing a novel waste disposal option to the residents. Additionally, the robot is aimed at optimising the waste transportation stream to increase the waste management efficiency. A visual illustration of the various stages of the concept is presented in Figure 50.

In the Hand-over phase, the Mobile Robot Container provides residents in the centre of Amsterdam with a convenient and accessible waste disposal option where they can deposit their waste at any time. The robot container will be stationed on the streets as parking spaces become available, in line with the transition of the city centre to a car-free environment in the near future. To comply with the regulations of Amsterdam, the maximum walking distance to the container is limited to 75 metres, which can be extended to 125 metres if necessary. (Overheid.nl, 2018) This parameter helps to determine the optimum number of robots required to effectively meet the waste collection needs of the residents. The implementation of a new waste disposal policy in the city centre, which involves depositing waste in the robot container, will replace the current practice of placing waste bags on the streets in Amsterdam. This will require residents to take personal responsibility for their waste until it is properly disposed of in the designated container, rather than simply leaving it on the street, which can lead to a lower sense of responsibility. As promoting perceived personal responsibility stimulates proper waste disposal behaviour (see Chapter 2), this new policy is potentially a more effective tool for encouraging residents to adopt proper waste disposal habits than the current policy. In addition, the replacement of the previous policy addresses related issues such as the dirty environment caused by waste bags left on the streets, which can have a negative impact on residents' quality of life and their relationship with waste. In addition, the new policy eliminates the need for manual collection of waste bags from the streets, reducing the physical strain on the employees of the department Schoon.

The Switch, the second phase of the Mobile Robot Container concept, aims to provide residents with continuous access to waste disposal facilities in order to prevent the emergence of negative stimuli that encourage littering behaviour, such as overflowing containers. To prevent full robot containers, the robot is equipped with an integrated press mechanism, which maximises its waste capacity and ensures efficient utilization of available space. Additionally, the system is designed to transmit a signal to the central hub when a robot reaches 95% capacity, prompting the dispatch of a new empty robot container. The full robot container then waits for the arrival of the empty one to arrive, ensuring that a waste disposal option is always available.

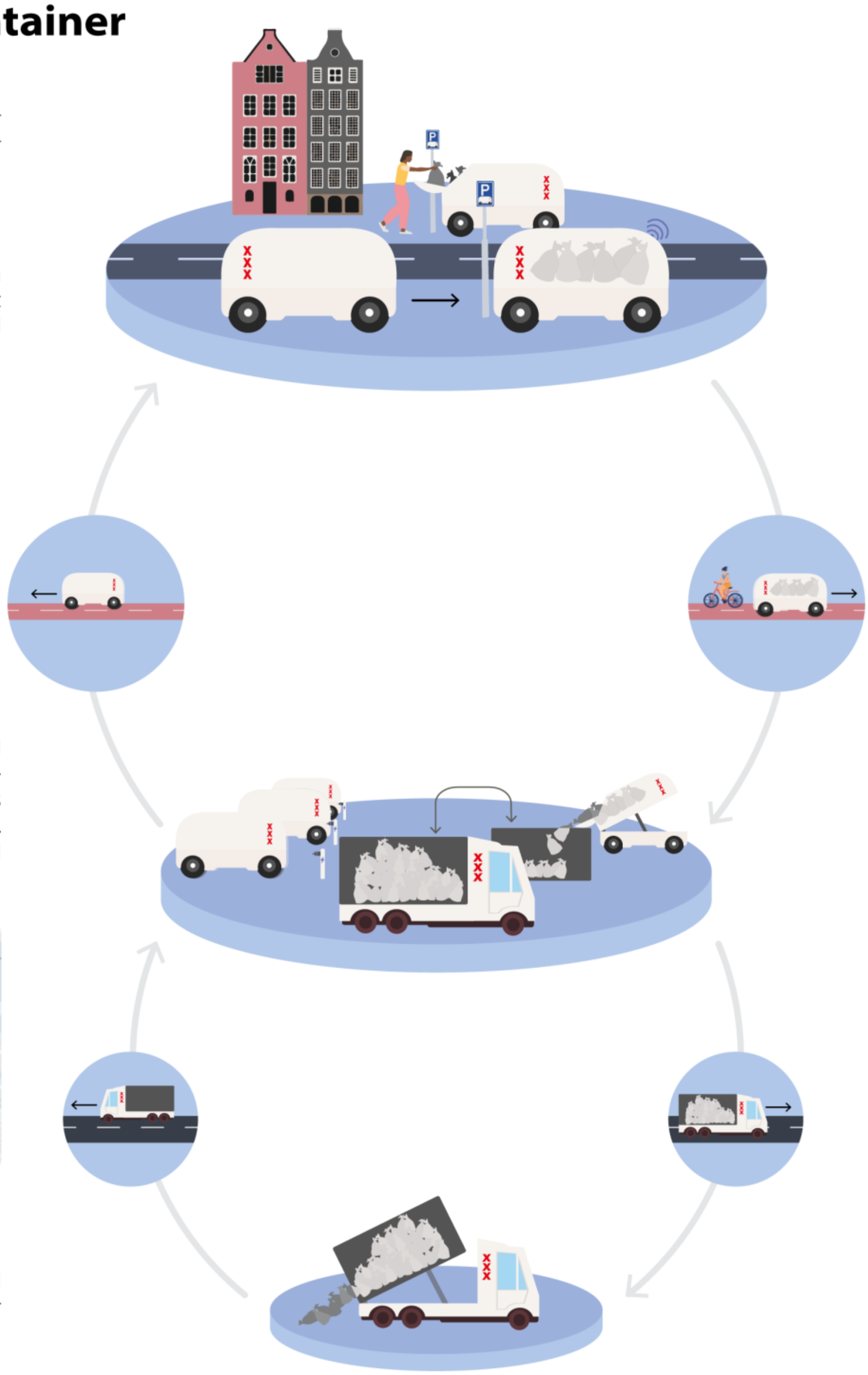
The third stage of the Mobile Robot Container concept, the Hub, involves the autonomous return of the full container to the hub after it has been replaced by an empty one, with the aim of optimising the efficiency of the waste stream. On arrival at the hub, the robot empties its contents into a regular container and recharges itself until it is needed again. By autonomously transporting waste to the hub, the robot eliminates the need for heavy trucks in the centre of Amsterdam, reducing the burden on fragile bridges and quays. To address the challenges of autonomously navigating complex urban environments, the robot container will operate on pre-determined short routes to the hubs via designated bicycle lanes at a maximum speed of 25 kilometres per hour (the maximum speed allowed on bicycle lanes is 30 kilometres per hour). (Ministerie van Infrastructuur en Waterstaat, n.d.-c) However, lower speeds may be considered to extend the autonomy of the robot. However, as the feasibility of autonomous driving may still pose problems in the coming decade, a monitoring system may be necessary during the initial implementation phase, allowing employees of department Schoon to intervene and manually control the robot if necessary.

The fourth stage of the Mobile Robot Container concept, Processing, involves transporting the waste from the hub to a designated collection point for further processing and recycling. As the hubs are located outside the city centre, they provide convenient access for waste collection vehicles to pick up the regular containers filled by the robots. This centralised collection of waste at the hubs improves the waste flow of transport and optimises the waste management process.

Mobile Robot Container

1 Hand-over
Residents can always dispose of their waste in the robot, with a hand-over point within 75 metres.

2 Switch
When the robot is 95% full, it requests a new one from the hub and waits for it to arrive, ensuring that a waste disposal option is always available.



3 Hub
The full robot drives to the hub, located outside the city centre, where it empties itself into a container and recharges while waiting for a dispatch request. When the container is full, it is loaded onto a waste truck for transport.

4 Processing
Waste in the container is transported by truck to a collection site for further processing and recycling.

Figure 50. This storyboard provides a visual representation of the Mobile Robot Container concept, showing its different stages to give a clearer understanding of the concept.

Appearance of the Mobile Robot Container

In order to maintain the identity of Amsterdam and to facilitate easy identification, the appearance of the Mobile Robot Container has been designed in a neutral white colour, which is widely used for waste collection vehicles in the city, together with the iconic three crosses of Amsterdam. Another option is to design the appearance of the robot containers in collaboration with Amsterdam-based artists to further build an Amsterdam identity.

According to the regulations, the maximum width of a bicycle with more than two wheels cannot exceed 1.5 metres (Ministerie van Binnenlandse Zaken, 2009), so the robot must be designed within these dimensions. The larger and heavier the robot, the more dangerous it becomes in the event of a collision, and a balance must be struck between these factors in the eventual development.

Service Blueprint Mobile Robot Container

In order to gain a more detailed understanding of the processes involved in the Mobile Robot Container concept, a Service Blueprint is developed and explained. This Service Blueprint, as shown in Figure 51, illustrates the underlying processes and interrelationships that enable the steps outlined in the previously mentioned storyboard.

In order to improve the visibility and understanding of the processes involved in the Mobile Robot Container concept, the Service Blueprint consists of several layers. The Resident actions layer illustrates the various steps taken by a resident in the process of disposing of their waste, while the Front-stage robot actions layer illustrates the visible actions of the robot when interacting with the resident.

The Back-stage actions layer includes the activities that take place behind the scenes to enable the service, which are not 'visible' to the resident. Again, as with the Mobile Robot Bin Service Blueprint, these actions are partially visible to the individual, as some actions take place in the urban environment. However, in order to maintain an overview, it was decided to maintain a line of visibility between the first two layers and the back-stage layers. The Back-stage robot actions layer describes the ‘invisible’ actions of the robot, while the Back-stage employee actions layer details the actions that a department Schoon employee takes to ensure the service of the robot container can function.

To make the Mobile Robot Container service work, a supporting background system is required. This system allows the robot containers to send a signal when they reach 95% capacity and need to be replaced. The system then dispatches an empty container from the hub to replace the full one. In addition, this system can facilitate optimised scheduling for the efficient emptying of the full regular bins at the hub by the trucks, further improving the overall efficiency of waste management practices.

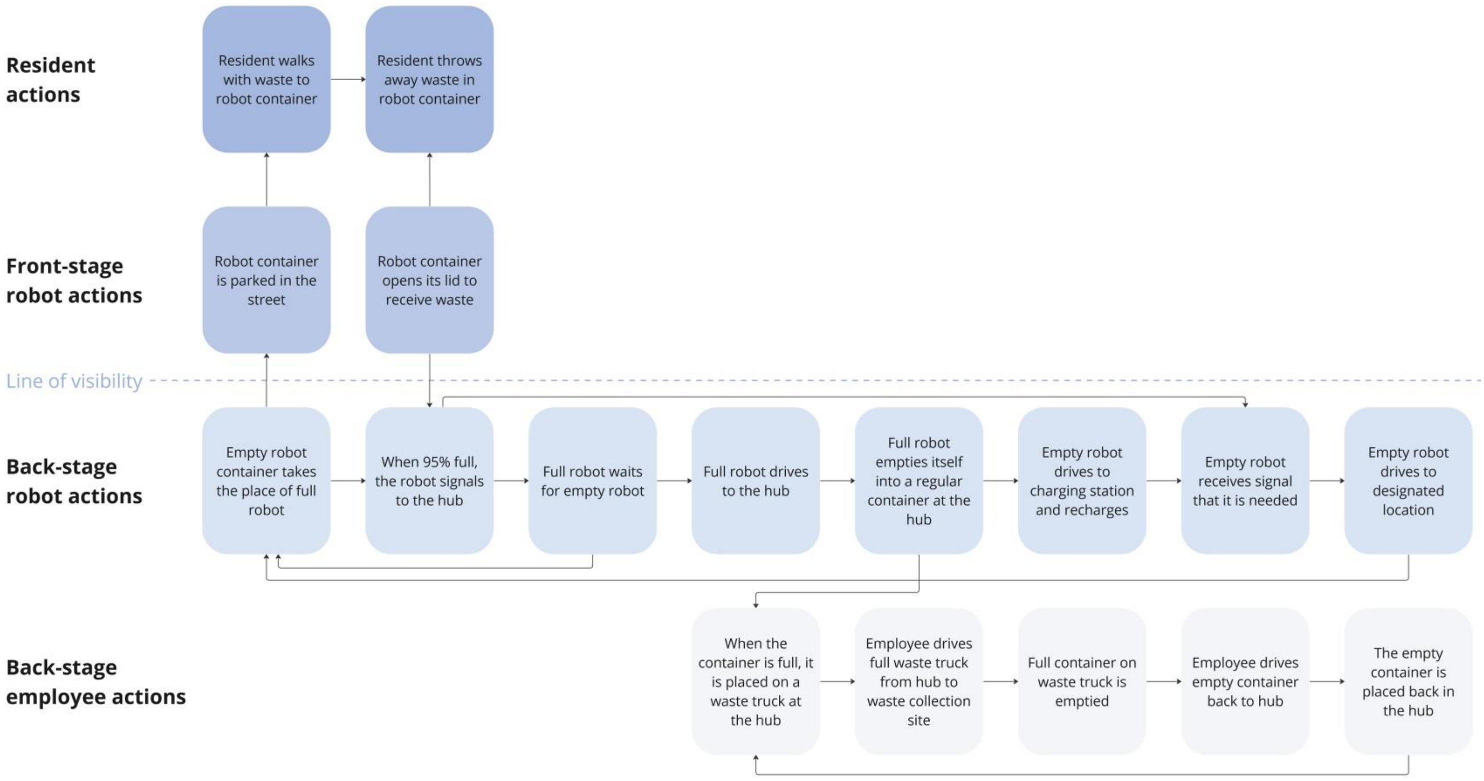


Figure 51. The Service Blueprint provides a visual representation of the Mobile Robot Container concept, showing the interconnected processes. To facilitate seamless coordination and communication between the containers and the hub, the implementation of a communication infrastructure is essential. This infrastructure enables the full robot containers to initiate a signal that triggers the dispatch of an empty Mobile Robot Container at the hub to increase waste management efficiency.

Benefits of the Mobile Robot Container

The deployment of the Mobile Robot Containers presents a range of benefits for both the waste management process and people in the urban environment. Among these benefits is the reduction of waste bags placed on the streets, resulting in a cleaner environment and the elimination of related issues, thereby reducing perceived nuisances from unclean surroundings experienced by residents. The system also offers improved waste disposal options for residents in the central area of Amsterdam, who currently have limited opportunities to dispose of their waste.

Furthermore, the Mobile Robot Containers promote individual responsibility for waste management as individuals retain ownership of their waste until it is deposited into the container. Additionally, the habit of placing trash bags on the streets is mitigated as the policy no longer permits the placement of waste bags on the streets.

Additionally, it mitigates the stress placed on bridges and quays by eliminating the need for heavy waste trucks to collect the waste. The deployment of the Mobile Robot Containers also reduces the physical demands on employees of department Schoon, as they are no longer required to manually handle heavy waste bags into the trucks. Furthermore, the concept streamlines the waste flow as the bins allow waste to be collected and automatically transfer the waste to the hubs when they reach capacity.

In addition, the Mobile Robot Containers are designed to operate autonomously, minimising the involvement of employees of department Schoon. The robot containers will be equipped with self-emptying and navigation capabilities, allowing them to operate independently. This increases capacity without the need for additional labour, addressing the department's labour shortage challenges and the potential growth of this challenge over the years.

Moreover, the Mobile Robot Containers are designed to operate autonomously, minimising the involvement of employees of department Schoon. The robot containers are equipped with self-emptying and navigation capabilities, allowing them to operate independently. This increases capacity without the need for additional labour, addressing the department's labour shortage challenges and the potential growth of this challenge in the Netherlands over the coming years.

7.3 Conclusion of the Two Robot Concepts for a Cleaner Amsterdam

In order to achieve a cleaner Amsterdam, it is essential that individuals remain involved in the waste management process, rather than relying on robots to take care of it when robots are deployed in Amsterdam (an insight gained in Chapter 5.1). In order to communicate this vision more effectively to the municipality of Amsterdam, two concepts have been developed in this chapter: The Mobile Robot Bin and the Mobile Robot Container.

In order to provide a comprehensive understanding of the benefits of the two concepts and their impact on the key values of the employees of department Schoon, as described in chapter 3.3, their influence on waste management behaviour by evaluating the triggered key factors influencing such behaviour, as described in Chapter 2, and their contribution to the waste management system of Amsterdam, a visual representation can be found in Figure 52. This visual overview serves as an illustrative means of assessing the concepts' alignment with the department's values, their ability to promote the desired waste management behaviours, and their potential added value to the overall waste management efforts in Amsterdam.

The visual representation shows the potential impact of the ReuzenRoomba concept, intended to clean the urban environment, on the key values of department Schoon employees. It indicates that this concept could have a negative influence on their values as it replaces the task of street sweeping, which is associated with many important values held by the employees. Furthermore, the concept has the potential to trigger motivators for littering behaviour, potentially leading to an increase in such behaviour.

In contrast, the concepts that involve individuals in the waste management process in Amsterdam demonstrate a different outcome. As depicted in the visual, these concepts ensure that the key values of the employees are safeguarded, as the robots serve as additional tools rather than replacements for their jobs. Moreover, the Mobile Robot container concept has the added benefit of positively impacting the key value of "disliking heavy physical tasks" by reducing the need for manually lifting heavy bags into trucks. Both the Mobile Robot Bin and Mobile Robot Container concepts also trigger motivators for proper waste management behaviour, further enhancing the value of contributing to a cleaner Amsterdam.

Thus, the visual emphasises the importance of maintaining individual involvement in the waste management process in the urban environment. It highlights the value of developing robots that not only align with employees' values, but also support their roles and responsibilities, while effectively promoting desired waste management behaviours and increasing waste management efficiency.

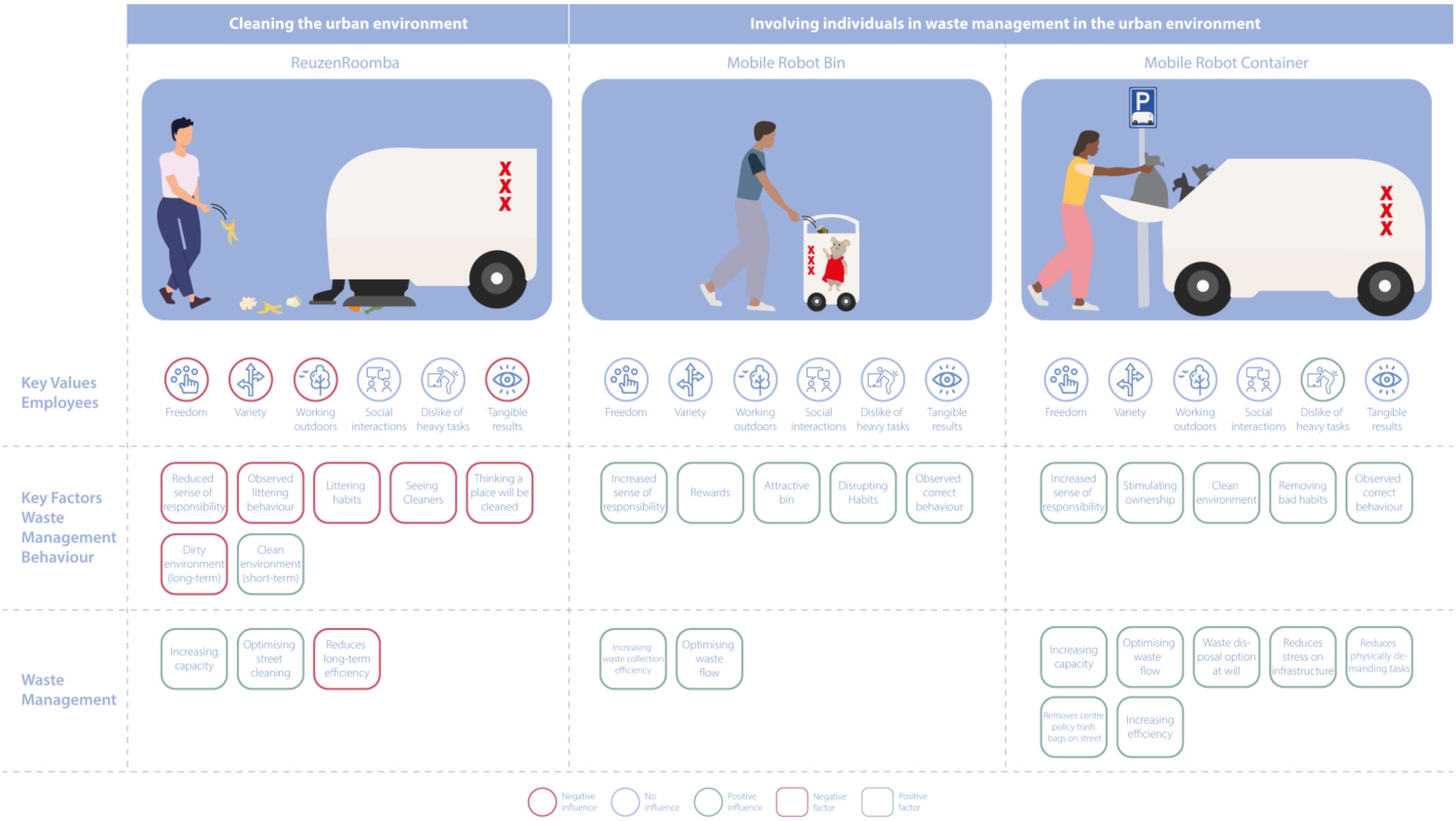


Figure 52. A visual comparison of the concepts' (and ReuzenRoomba's) alignment with the department's values, their ability to promote the desired waste management behaviours, and their potential added value to the overall waste management practices in Amsterdam. This visual highlights the benefits of the two proposed concepts and the importance of maintaining individual involvement in the waste management process in the urban environment. The legend of the colour codes can be found at the bottom of the visual.

To provide a visual representation of the potential future landscape of Amsterdam with the implementation of the Mobile Robot Bin and the Mobile Robot Container, the future vision of this thesis is presented in Figure 53. This vision depicts a scenario in which these robots play a significant role in creating a cleaner and more liveable Amsterdam.

In this future vision, the robots contribute to a cleaner and therefore more liveable Amsterdam through the combined efforts of humans and robots, using the robots as proactive agents to promote proper waste management behaviour and resident ownership, and to improve the efficiency of waste management.

In order to assess the perceived value of implementing the proposed robot concepts in achieving a cleaner Amsterdam, it is essential to involve key stakeholders, including the municipality of Amsterdam and the department Schoon. Given their expertise and knowledge of the municipality's requirements and waste management challenges, these stakeholders will play a crucial role in evaluating the suitability and desirability of the proposed robot concepts in their potential to contribute to a cleaner Amsterdam. In addition, given the AMS Institute's extensive expertise in anticipating Amsterdam's future prospects and challenges, as well as its expertise in developing sustainable solutions that integrate scientific knowledge with societal needs, it is crucial to involve their expertise in the evaluation of the proposed robot concepts. Therefore, an evaluation with representatives of the AMS Institute will be carried out to assess the feasibility of the proposed robot concepts in the future Amsterdam.

Figure 53. A visual representation of how robots can potentially be deployed in Amsterdam to achieve a cleaner city. They are intended to act as proactive agents to encourage proper waste management behaviour and resident ownership, as well as to improve the efficiency of waste management.

8

Evaluation with the Municipality of Amsterdam, Department Schoon and AMS Institute

8 Evaluation with the Municipality of Amsterdam, Department Schoon and AMS Institute

To gain a better understanding of the suitability and feasibility of the proposed robot concepts for a cleaner Amsterdam, an evaluation will be conducted with the involvement of relevant stakeholders, including the municipality of Amsterdam and department Schoon. In addition, an expert from the AMS Institute will be consulted to leverage the Institute's expertise on the future developments in Amsterdam, with the aim of enhancing the compatibility of the robot concepts with the future prospects of Amsterdam. The details of the feedback session methodology can be found in Chapter 8.1, while the outcomes of the municipality's feedback are presented in Chapter 8.2, and those of the AMS Institute in Chapter 8.3. A conclusion of the findings will be presented in Chapter 8.4.

8.1 Method

To determine the value of the proposed robot concepts for a cleaner Amsterdam and assess their compatibility with future developments, two feedback sessions were conducted with key stakeholders and experts. The methodology used in both sessions will be outlined in the following sections.

Feedback session with the Municipality of Amsterdam and Department Schoon

Given the demanding schedules of the participants and their different locations, it was decided to conduct the feedback sessions online using Zoom, while Miro was used for the presentation and feedback exercises. The session consisted of five components, which will be described below.

The objective of the first component of this session was to find out whether the participants had a preconceived notion of the added value of a cleaning robot prior to the presentation. To achieve this, participants were asked to write down two robots that could be beneficial to Amsterdam by using pre-placed post-its on a provided template, see Figure 54. The received responses were used to determine whether the municipality could be convinced by the current presented narrative of the importance of robots that ensure a good waste relationship.

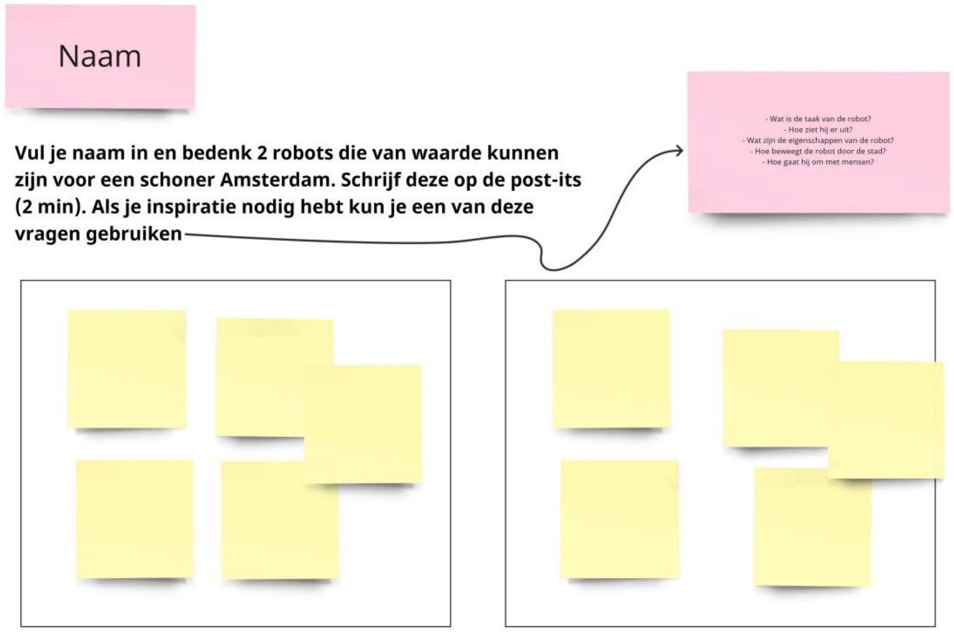


Figure 54. The template used to find out if the participants had a preconceived notion of the added value of a cleaning robot before the presentation. The answers were compared with the answers in the fourth part to see if the stakeholders could be convinced by the presented narrative.

The second part consisted of a comprehensive presentation that covered the background information of this thesis related to the problem statement, the research question of the thesis, and the outcomes of relevant developments of Chapter 3 and 4. This was followed by a demonstration of the autonomous cleaning robot, the ReuzenRoomba, as a thought experiment to illustrate its adverse effect on the waste relationship and its consequences, thereby emphasising the requirement for a more suitable alternative. The presentation also delved into the key factors that influence the waste relationship and provide an analysis of the three prevalent waste management issues in Amsterdam. Finally, a brief overview of the two robot concepts and their potential benefits to the waste management system was presented.

In the third section of the session, the participants were asked for their feedback on the two proposed concepts. To obtain a comprehensive evaluation, four questions were formulated for the participants to answer using a template in Miro. These questions were designed to assess the functionality of the robot in Amsterdam, its strengths, the challenges it may face, and any other thoughts, comments, or feedback the participants may have. The last question is considered in interview techniques to be the most crucial as it has the potential to yield insightful and unanticipated answers. (Patton, 2002)

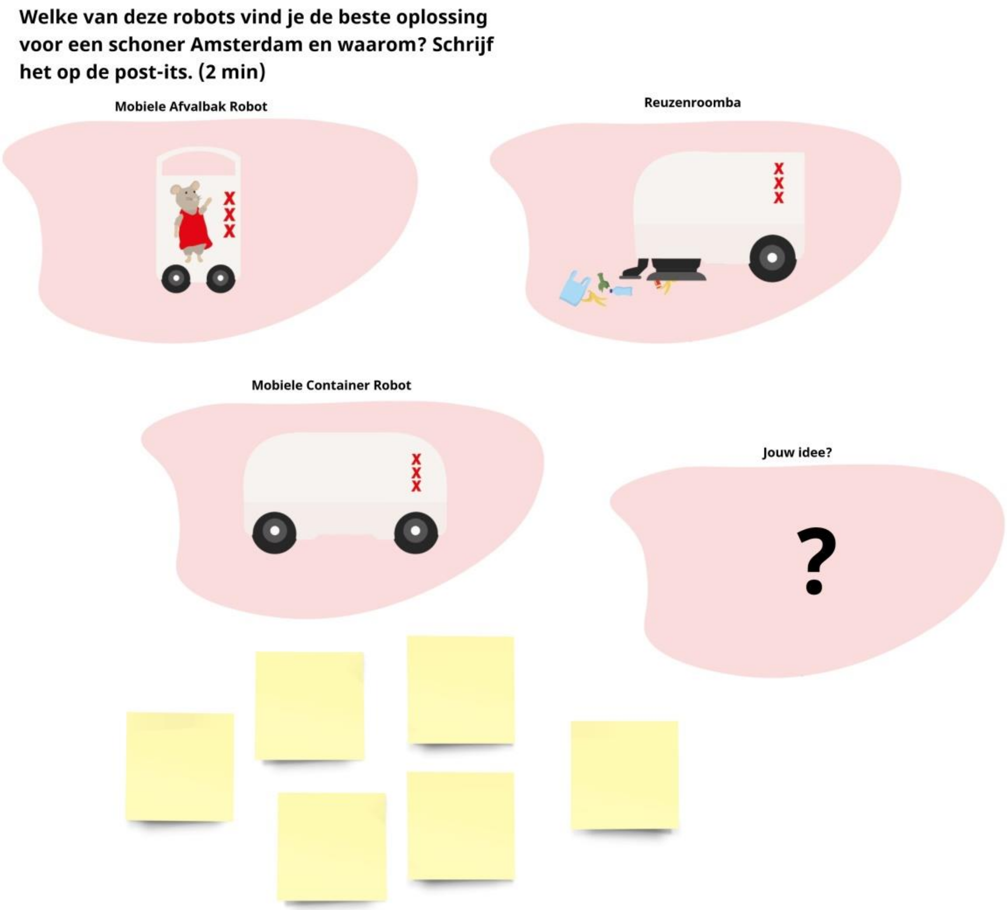


Figure 55. This template was used to find out whether the presented narrative could convince the stakeholders. This could be determined by comparing the answers in this template with the answers in the template in Figure 54.

In the fourth part, participants were asked to choose which robot they thought would be most effective in Amsterdam, namely the ReuzenRoomba, the Mobile Robot Bin, the Mobile Robot Container or their own idea (from the assignment in the first part), see Figure 55. The latter two options were included to assess the participants' preferences for a cleaning robot or any other alternative solution they may have. The results of this evaluation would indicate the success of the second objective, which was to determine the effectiveness of the current narrative in convincing the participants of the significance of robots that ensure a good waste relationship.

In the final part, after the participants had filled in their responses, an opportunity was provided for them to discuss their feedback and ask questions. The objective of this discussion is was to obtain more comprehensive and in-depth feedback from the stakeholders.

Feedback session with the AMS Institute

Given the AMS Institute's expertise on the future developments in Amsterdam, it was considered useful to seek their input on the robot concepts in order to optimise their compatibility with the future of Amsterdam. A virtual meeting was conducted via Zoom at the request of the participant. During the meeting, a brief presentation was delivered to a representative of the AMS Institute, outlining the obtained insights and the two robot concepts.

After the presentation, a pre-determined set of questions was posed to the participant to elicit feedback on the robot concepts. These questions covered the robot's functionality in Amsterdam, its strengths, the challenges it may encounter, any additional thoughts, comments, or feedback the participant might have, and which concept could add the most value to a cleaner Amsterdam. The session concluded with a discussion aimed at obtaining further comprehension and exploration of the participant's feedback.

During this discussion, the representative of the AMS Institute provided recommendations for implementation activities. Consequently, it was considered valuable to present the roadmap that had been developed, outlining the activities necessary for the municipality to implement the proposed concepts, for further discussion and evaluation. It is important to note that this roadmap had already been developed based on the feedback session with the municipality, where it was requested. A detailed exploration of this roadmap can be found in Chapter 9.

8.2 Feedback from the Municipality of Amsterdam and Department Schoon

To better align the proposed concepts with the needs and preferences of the municipality of Amsterdam and the department Schoon, a presentation was given. In addition to gathering feedback, another key objective of this session was to evaluate whether the narrative presented could convince the stakeholders of the importance of incorporating waste-relationship factors in the design of a robot and to demonstrate that a cleaning robot such as the ReuzenRoomba is not an optimal solution. The goal was to gain the stakeholders' support and convince them of the necessity of considering the waste relationship in the development of robots.

The participants were Ruben van Thal, the group leader of department Schoon in the centre of Amsterdam, and Antina Snijders, Bestuursadviseur Stadswerken at the municipality of Amsterdam. They were selected due to their diverse perspectives and expertise, which were expected to provide insightful and varied feedback. Furthermore, they represented the key stakeholder groups.

Obtained Feedback

During the session, the two concepts were evaluated and feedback was received from the stakeholders. The outcomes of the evaluation are summarised below, and the filled feedback forms are available in Appendix E. Due to the small and intimate group dynamic, the participants were encouraged to share their thoughts and questions freely. Both participants expressed high levels of positivity regarding the concepts and deemed them viable and valuable for implementation in Amsterdam. Moreover, they inquired about the specific activities that need to be undertaken to facilitate the deployment of these robots in Amsterdam.

An analysis of the assignment in section one and four revealed that a shift in perspective had occurred. The participants unanimously selected the Mobile Robot Container in the final task of the session, rather than opting for the ReuzenRoomba or any other autonomous cleaning robot. This highlights a successful outcome of the second objective, which was to assess whether the presented narrative could convince the stakeholders of the significance of incorporating waste-relationship factors in the design of the robot. During the demonstration of the ReuzenRoomba, a participant even suggested the implementation of a moving bin, which is noteworthy as this aligns with one of the proposed concepts.

Mobile Robot Container
The outcome of section four was the unanimous selection of the proposed Mobile Robot Container as the preferred solution for a cleaner Amsterdam. The participants expressed that this concept provided a major advantage in terms of waste management and disposal in Amsterdam, as the current policy in the centre (placing garbage bags on the street) generates a significant amount of litter in the area and is too burdensome for the weak quays and bridges. Furthermore, they noted that residents would be optimally facilitated and able to dispose of their household waste whenever they needed to. The participants recognised the convenience and efficiency of this concept, which would benefit both department Schoon and the Waste & Raw Materials department, they said. The elimination of heavy physical labour for the employees of department Schoon and illegal waste disposal on the streets were cited as key benefits. In addition, the robot's zero-emission capability was recognised as another benefit, being in line with Amsterdam's objective of reducing emissions and having all vehicles within the city run electrically by 2030.

However, the participants also acknowledged potential challenges, such as illegal dumping by business owners and the potential for vandalism. Additionally, the limitations of the current energy infrastructure for charging the containers were noted, as there have already been challenges in charging electric vehicles at the Schoon department.

In addition, some suggestions were made to improve the implementation of the mobile robot container, including the possibility of the robot emptying itself into a boat, as Amsterdam is already doing trials with transporting trash from the city centre via water. Another suggestion is to personalise the robots by giving them a name, to make the robots more personal to residents or the neighbourhood and to foster community ties.

Mobile Robot Bin
Both participants were positive about the Mobile Robot Bin concept and saw its potential as an effective litter prevention solution. In addition, they highlighted the need for solutions that address people's littering behaviour, further emphasising the relevance of this concept. One participant pointed out to past trials of talking trash bins

in Amsterdam and the resulting decrease in litter in the area. The flexibility of the Mobile Robot Bin, which can be deployed where it is most needed, was also highlighted as a benefit. Both participants felt that the robot would be a good fit in Amsterdam, with one participant expressing interest in conducting a trial.

However, some challenges were identified with this robot, such as potential abuse, where the robot may be misused, such as racing with children or disposal of inappropriate items (such as stones or branches) due to the perceived fun of the interaction. Vandalism was also identified as a potential issue, as the robot may attract attention and potentially be damaged by people (under the influence) in the centre. Another challenge is the current practices of homeless individuals who collect items with deposits from trash bins, leading to the cans being left open and damaged, causing litter in the surroundings. Additionally, the possibility of dangerous situations in crowded areas with pedestrians was mentioned, as the robot could potentially collide with them.

Conclusion Feedback Municipality Amsterdam and Department Schoon

In conclusion, the stakeholders evaluated both concepts as suitable for Amsterdam and raised the question of next steps for implementation. Accordingly, a roadmap will be developed to provide the stakeholders with a comprehensive outline of the activities required for the deployment of the proposed robots.

Moreover, the participants unanimously agreed that the Mobile Robot Container would have the greatest potential value for achieving a cleaner Amsterdam. One participant emphasised its potential for tackling a key problem, stating that the waste bags contribute to a significant amount of litter in the city centre and that it would offer a more efficient waste disposal solution to tackle this problem. Another mentioned key benefit was the elimination of heavy physical labour for the employees of department Schoon, as is currently required when trash bags are collected from the streets in the city centre. This collective agreement on the Mobile Robot Container further validates the achievement of the second objective, which was to assess how compelling the presented story is in conveying the importance of integrating key factors of waste management behaviour into the robot's design.

To ensure successful implementation, considerations must be given to preventing vandalism, illegal waste disposal, and misuse of the robot. Safety measures for individuals during robot deployment must also be considered, along with devising solutions for the challenge of charging the robots.

Additionally, suggestions were made to enhance the implementation of the Mobile Robot Container. These suggestions include enabling the robot to empty itself into a boat, aligning with Amsterdam's current trials of transporting waste via water, and personalising the robots by assigning them names. The intention behind personalisation is to establish a more personal connection between residents and the robots, fostering community ties.

8.3 Feedback AMS Institute

In order to assess the potential feasibility and viability of the proposed robot concepts in the future of Amsterdam, a feedback session was held with a representative of the AMS Institute, namely Thijs Turel, a program manager of the Urban Data and Intelligence program. He is specialised in developing projects that use urban big data and intelligence to enhance urban life, making him well suited to provide feedback in the context of this thesis, which aims to improve the quality of life in Amsterdam by implementing robotic solutions to facilitate a cleaner city. As there was only one participant, Thijs Turel was encouraged to share his thoughts and questions freely during the presentation in order to gain deeper and more comprehensive insights and feedback.

Obtained Feedback

Thijs Turel expressed his agreement with the presented future prospects of Amsterdam during the presentation and shared the view that individuals should be held responsible for their own waste management. He stated that "both robot concepts are desirable" as the robots do not engage in cleaning tasks and collecting waste from the ground for humans. He argued that such an approach is preferable because it prevents people from taking pleasure in throwing waste in front of robots to watch them pick it up. If such littering behaviour is made enjoyable by the presence of cleaning robots, it could result in the need to deploy more robots to tackle the growing problem of littering behaviour, thereby reinforcing this undesirable behaviour, he stated. Consequently, deploying autonomous cleaning robots to achieve a cleaner Amsterdam could be counterproductive, he concluded, aligning with the vision of this thesis.

When asked which robot concept is most suitable for a cleaner Amsterdam, Thijs Turel replied that both robot concepts are suitable for contributing to a cleaner Amsterdam, as each robot addresses a different issue. He praised the thesis as a "very nice preliminary study" and stated that "with this thesis we now really know what we are talking about and it has eliminated a lot of unrealistic ideas, making it the perfect groundwork for the municipality to take the next step. This is the exploration you need to do to make sure you are doing things that will solve the problems, because with this thesis it is nicely narrowed down. It would be a shame if this was lost. This is something we have to keep working on." He emphasised the need for further exploration of the topic, given the real issues at hand, emphasising that the solutions cannot be realised overnight.

Mobile Robot Container

In relation to the Mobile Robot Container, Thijs Turel expressed his view that "the container concept is strong and feasible for implementation in Amsterdam." He envisioned the container moving slowly on bike paths, ensuring a predictable and "boring" movement, which he believes is essential. He also suggested that the container could operate during quiet periods on the roads. Thijs Turel stated that "although there are currently legal obstacles, the possibility of incorporating robots in the city centre in the future can be considered as plausible." He therefore considered the Mobile Robot Container to be a "very nice idea" worthy of consideration.

Furthermore, Thijs Turel expressed concerns about the costs involved in the implementation of the Mobile Robot Container, stating that "it is important to explore ways to minimise the equipment required in robots, given that robots are expensive." However, he acknowledged the need for the robot to be able to operate autonomously, and that by the time the robot reaches the hub, the method of emptying the container (manual or automatic) would not make much difference in costs, therefore he believed that the current equipment of the concept was acceptable. Additionally, he suggested that it would be interesting to integrate the robot container with the Roboat, as it employs the same mechanism, but over water. He stated that the preferred option is to transport waste by water. If transportation by water is not possible, which is usually the case in the city centre, transportation by road could be an option.

Turel further stated that the Robot Container may encounter difficulties when crossing the canals over steep bridges. Despite this challenge, Turel recognised the potential benefits of using the Robot Container in the centre of Amsterdam. He said that the Robot Container, in comparison to the Robot Bin, is a “less futuristic idea, although it will not be easy to make such a robot. Nevertheless, it is essentially an autonomous driving container that takes good advantage of Amsterdam's future prospects, such as the establishment of logistical hubs and the extra space available in the city centre as fewer cars will be present."

Mobile Robot Bin

Thijs Turel noted that the Mobile Robot Bin could potentially face more implementation challenges than the Mobile Robot Container. In particular, he expressed concern that vandalism could be a greater issue with the Mobile Robot Bin, especially among tourists, as people are not yet accustomed to the presence of robots in urban environments. Given the novelty of the Robot Bin, individuals may become curious and exhibit behaviours that could result in vandalism. Turel suggested that the implementation of the Robot Bin may be of interest to a European waste management company that operates in several European cities, including popular tourist destinations like Prague, London, and Paris. The rationale behind this suggestion is that the novelty of the Robot Bin would wear off more quickly in these major tourist cities, resulting in tourists' waste disposal behaviour becoming more closely aligned with that in Amsterdam, he explained. As a result, the Robot Bin could become a recognisable component of the waste management system, creating established models of expected waste management behaviour across several cities. Therefore, he suggested that it could be valuable for European tourist cities to collaborate in implementing the Robot Bin collectively.

To tackle the challenges posed by vandalism and hooliganism, which must be addressed effectively, Turel suggested some solutions. He raised the question of whether to deploy cameras to monitor and penalise those who damage the robots, or to have a human supervisor present on-site. He proposed an introductory period of five years, during which supervisors would be present to mitigate any related issues. Subsequently, once the initial novelty has worn off, the bins could be left unattended, eventually losing their appeal to individuals, which would reduce the risk of vandalism. However, Turel noted that addressing vandalism for both robot concepts would require a new design challenge.

The Implementation Strategy Roadmap

Following the presentation, the expert provided recommendations regarding the activities necessary for deploying the robots in Amsterdam. It is worth noting that all of these recommendations had already been incorporated into the existing roadmap outlined in Chapter 9. Subsequently, the roadmap illustrating the required activities was presented to Thijs Turel, who expressed agreement with its content. Turel did not provide any further comments or suggestions for additional additions or modifications.

Conclusion Feedback AMS Institute

In conclusion, Thijs Turel shared the view that individuals should remain responsible for their own waste management when deploying robotic solutions. He considered the possibility of deploying robots in the city centre in the future plausible and indicated that both proposed robot concepts are desirable, as they both involve humans in the waste management process. Additionally, Turel stated that both robot concepts are suitable to contribute to a cleaner Amsterdam, as each robot addresses a different problem.

However, he acknowledged the potential challenges involved in the implementation of both robot concepts, including legal obstacles, costs, addressing vandalism and the difficulty of navigating steep bridges. Despite these challenges, Turel has expressed optimism regarding the feasibility and added value of the Mobile Robot Container concept in Amsterdam, citing its alignment with the city's future prospects, which include the establishment of logistics hubs and the availability of additional space due to a reduction of cars in the centre. Additionally, Turel suggested that integrating the robot container with the Roboat, which utilises a similar mechanism over water, would be an interesting possibility.

Furthermore, he suggested that the Robot Bin could be of interest to a European waste management company that could collaborate with European tourist destinations to introduce this technology as a recognisable part of their waste management systems. The aim would be to model the expected waste management behaviour across different cities and accelerate the reduction of the novelty factor of robots in key tourist areas, to reduce vandalism.

Furthermore, Thijs Turel's recommendations for activities needed to deploy robots in Amsterdam were already included in the existing roadmap outlined in Chapter 9. The proposed roadmap, which contains the necessary activities for successful implementation, was approved by Turel without any additional comments or suggestions when it was shown. Moreover, Turel considered the thesis as a valuable preliminary study and a useful foundation for the municipality to take the next steps. He emphasised the need for further investigation into the topic, specifically in terms of addressing the challenge of vandalism, which presents a new design challenge. Turel highlighted the importance of keeping up with the momentum and continued efforts to achieve a cleaner Amsterdam.

8.4 Conclusion Evaluation with the Municipality of Amsterdam, Department Schoon and AMS Institute

Overall, the feedback sessions provided valuable insights on the two robot concepts. Representatives from the municipality of Amsterdam, the department Schoon, and the AMS Institute expressed positivity and recognised the potential value in both concepts. However, the Mobile Robot Container received unanimous agreement as the concept with the highest potential and feasibility for achieving a cleaner Amsterdam. Its potential to address a key issue was highlighted, as waste bags contribute to a significant amount of litter in the city centre and the Mobile Robot Container would provide a more efficient waste management solution to address this problem. Another key benefit mentioned was the elimination of heavy physical labour for the employees of the department Schoon, which is currently required when collecting waste bags from the streets in the city centre.

The stakeholders raised questions about the subsequent development steps after the thesis, showing enthusiasm for the outcomes and agreeing on the importance of individual responsibility in waste management when deploying robotic solutions. As a result, a roadmap outlining the necessary activities has been created, detailed in Chapter 9.

In addition, during the feedback session with Thijs Turel, the already developed roadmap, as requested by the municipality, was presented and discussed. He expressed his approval of the roadmap, without having any additional recommendations. He considered this thesis to be a valuable preliminary study, providing a solid foundation for the municipality's future efforts, and stressed the need to maintain the momentum of the on-going efforts for a cleaner Amsterdam.

However, several challenges were identified in the feedback sessions that must be addressed before implementing robots in Amsterdam. These challenges encompass issues such as vandalism, illegal waste disposal, misuse of robots, ensuring safety during deployment, establishing charging infrastructure, overcoming legal obstacles, managing development costs, and navigating obstacles posed by steep bridges. Nonetheless, Turel expressed optimism regarding the feasibility and value of the Mobile Robot Container concept in Amsterdam, emphasising its alignment with the city's future prospects, including the establishment of logistics hubs and the availability of additional space resulting from car-free initiatives in the city centre. Furthermore, Thijs Turel emphasised the need for further research into the topic and challenges, in particular to address the challenge of vandalism, which he noted was a completely new design challenge. These identified challenges should be thoroughly researched to improve the practical deployment of robots and will be included in the recommendations in Chapter 10.3 for further consideration.

Additional Suggestions for the Robots

Several noteworthy suggestions were made by the stakeholders to enhance the robot concepts. One recommendation for the Mobile Robot Container is to enable self-emptying into a boat, potentially utilising the boat currently employed by the municipality in a trial of waste transportation via water. Furthermore, an additional recommendation is to explore the integration of the Mobile Robot Container with the Roboat as the Roboat operates with a similar mechanism of autonomous waste transport over water. Combining the capabilities of the Mobile Robot Container with the Roboat could improve the waste flow and further optimise the efficiency of waste management in Amsterdam. This integration would enable a coordinated approach to waste management, leveraging both land-based and water-based robotic solutions. Another suggestion is to personalise the Mobile Robot Containers by giving them personal names, with the aim of creating stronger connections between residents and promoting community involvement.

As for the Mobile Robot Bin, a suggestion was made to explore its potential appeal to a European waste management company that could collaborate with various European tourist destinations and integrate this technology as a recognisable part of their waste management systems. This collaborative approach seeks to establish a model for expected waste management behaviour across different cities and accelerate the reduction of the novelty factor associated with robots in prominent tourist areas, ultimately reducing vandalism.

9
Implementation Strategy Roadmap

9 Implementation Strategy Roadmap

During the evaluation process involving stakeholders from the municipality of Amsterdam and the department Schoon, it became evident that there was a shared recognition of the potential and value in deploying the Mobile Robot Container and Mobile Robot Bin in Amsterdam, as they perceived both robots as valuable in achieving the goal of creating a cleaner Amsterdam. Therefore, it was decided to include both in the roadmap, although the stakeholders unanimously agreed that the Mobile Robot Container would have the greatest added value in achieving a cleaner Amsterdam. This decision was based on the stakeholders' common recognition of the value of the Mobile Robot Container in tackling another specific waste problem in Amsterdam, namely littering behaviour.

During the evaluation session, the municipality of Amsterdam and department Schoon inquired about the specific activities to be undertaken to successfully implement these robotic solutions. Therefore, to provide the stakeholders with a more concrete plan for a successful implementation of both robots for achieving a cleaner city, a roadmap has been developed in this chapter. This method helps to create a visual overview to see what activities are needed to implement the proposed concepts. Furthermore, the roadmap can be perceived as an essential tool for engaging stakeholders in discussions and aligning future plans and activities. This aspect is particularly crucial considering the complex and time-consuming nature of developing robots, which involves multiple stakeholders. (Simonse, 2018)

Due to the municipality of Amsterdam's desired objective of deploying an innovative product service involving the proposed robots alongside their existing waste management methods, which requires a substantial time frame for development, they will face limitations in terms of knowledge and internal resources for robot development. Therefore, the engagement of external parties becomes crucial in order to successfully realise this innovative product service. Although not being directly involved in robot development, the primary objective of this roadmap is to effectively communicate the necessary activities that the municipality of Amsterdam must undertake, as per their specific request.

Chapter 9.1 provides a comprehensive explanation of the methodology used to develop the roadmap. Subsequently, Chapter 9.2 will describe the detailed activities that are essential for the successful deployment of robots in Amsterdam as outlined in the roadmap. Finally, Chapter 9.3 will provide a conclusion.

9.1 Method

Given the objective of effectively communicating the necessary activities for the municipality of Amsterdam, it has been determined that conventional roadmap methods, such as those proposed by Simonse (2018) and Kim & Agogino (2015), may not be suitable for addressing this specific objective. These commonly used methods typically include elements such as user values, market segmentations, product services and technology applications. However, since the emphasis here is on communicating the required activities, these elements become less relevant in this particular context. Therefore, an alternative approach that emphasises the communication of specific activities will be explored to better serve the intended purpose of the roadmap.

To address this, a customised method will be used for the roadmap, with a clear depiction of the activities that the municipality must undertake in different areas in order to realise the future vision and to achieve the objective of effective communication of the activities to the stakeholders. This customised methodology is described next.

Four Elements

The development and deployment of the Mobile Robot Bin and the Mobile Robot Container require attention in several areas that are essential for their successful implementation. These areas include Social Embedding, Practical Embedding, Human-Robot Interaction, and Development.

The first element, Social Embedding, focuses on ensuring the social integration of the robot into the city of Amsterdam, as it will interact with people in the urban environment. Activities related to social embedding aim to determine how the robot can fit seamlessly into the urban context. This involves considering the social and cultural aspects of the city and identifying strategies to integrate the robot in a way that is accepted and embraced by the community.

The second element, Practical Embedding, is concerned with integrating the robot into Amsterdam on a more practical level, such as in terms of infrastructure. This involves evaluating the existing infrastructure and determining what modifications or adaptations are needed to effectively accommodate the robot. Practical embedding ensures that the robot can navigate the physical environment of the city and perform its intended tasks efficiently.

The third element, Human-Robot Interaction, focuses on the specific interactions between humans and the robot. Unlike social embedding, which emphasises the role of the community in integrating the robot into the city, HRI examines the design and implementation of interfaces, communication channels and overall interaction mechanisms between people and the robot. This element emphasises the creation of a positive and intuitive user experience, taking into account factors such as ease of use, clarity of communication and user satisfaction.

The final element is Development, which includes the interdisciplinary collaborative activities needed to develop the robot. It should be noted that the municipality will not be developing the robot itself, so the focus in this element is on the activities that the municipality needs to take in order to steer the development in the right direction. Iterative improvements will be needed to ensure that the robot meets the required specifications and functions effectively.

By addressing these four elements, the municipality can manage the complexities involved in the development and deployment of the Mobile Robot Bin and Mobile Robot Container concepts more effectively and ensure a more successful integration of the robots in Amsterdam.

Three Horizons

The roadmap is divided into three horizons, inspired by the Three Horizons model proposed by Simonse (2018) as a long-term strategy for innovation. However, adjustments have been made to align with the objective.

In this customised approach, the focus lies on displaying the required activities while adjusting the initial phase of the method of Simonse (2018). Instead of prioritising the enhancement of design value for current products or services in the first horizon, the emphasis is placed on identifying and mapping the necessary specifications for robot development, ensuring their long-term value in promoting a cleaner Amsterdam. The rationale behind this adaptation is the absence of an existing robot service, which means enhancement is not yet possible. Nevertheless, the municipality is currently actively exploring novel waste management methods, which can be considered as improving the current service. However, since these activities do not directly contribute to the realisation and implementation of the robots, they are not included in the roadmap's activities toward achieving the deployment of the robot.

The second horizon serves as a bridge between the development of the future vision in the third horizon and the initial phase. Its main objective, derived from the method of Simonse (2018), is to enhance the user value. Within the context of this roadmap, the focus is on improving the eventual user value in order to increase the likelihood of user acceptance and facilitate the successful integration of the robots into the city of Amsterdam. This objective is accomplished through the implementation of pilot projects followed by a thorough evaluation of their outcomes.

The third horizon focuses on the realisation of the future vision, in line with the objective of the third horizon of Simonse (2018). In this particular context, the focus is on the development and implementation of robots, with the ultimate goal of achieving a cleaner Amsterdam.

The activities in each horizon will be described in more detail next.

9.2 The Horizons of the Implementation Strategy Roadmap

In order to facilitate effective communication of the activities required to realise the Mobile Robot Container and Bin, a roadmap has been developed and presented in Figure 56. This provides a visual representation of the broad outline of the activities required to achieve the desired future vision. A description of these activities is given in the following sections.

The roadmap distinguishes between activities to be carried out by internal stakeholders within the municipality and those that require collaboration with external parties, such as research institutions or robotics companies. For clarity, the roadmap uses a colour coding system to indicate the division between activities to be undertaken by the municipality, light blue, and those involving external parties, dark blue.

It should be noted that a crucial prerequisite is the establishment of an internal project team within the municipality to lead and manage the project. At the beginning of this roadmap, it is assumed that such a project team has already been formed within the municipality of Amsterdam.

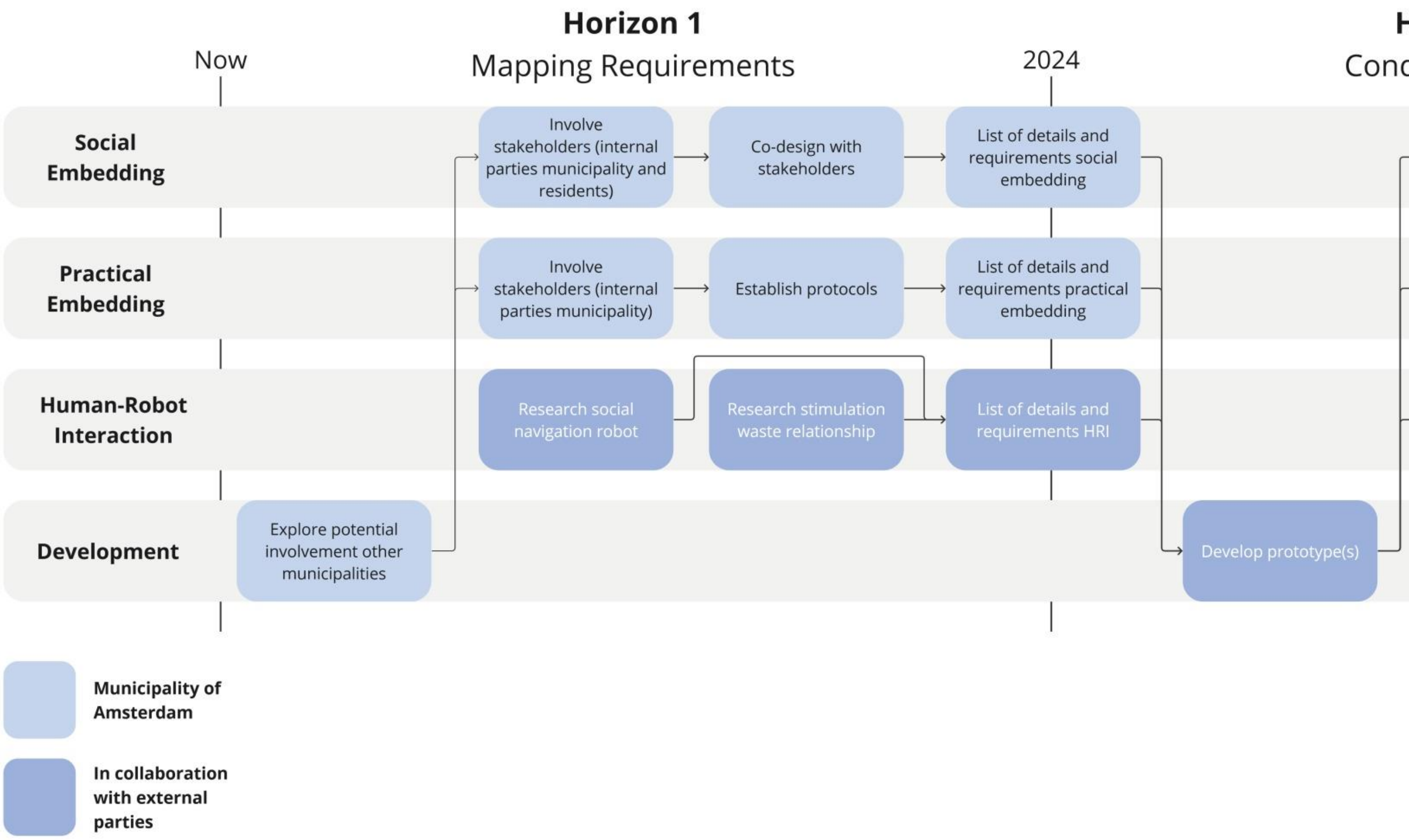
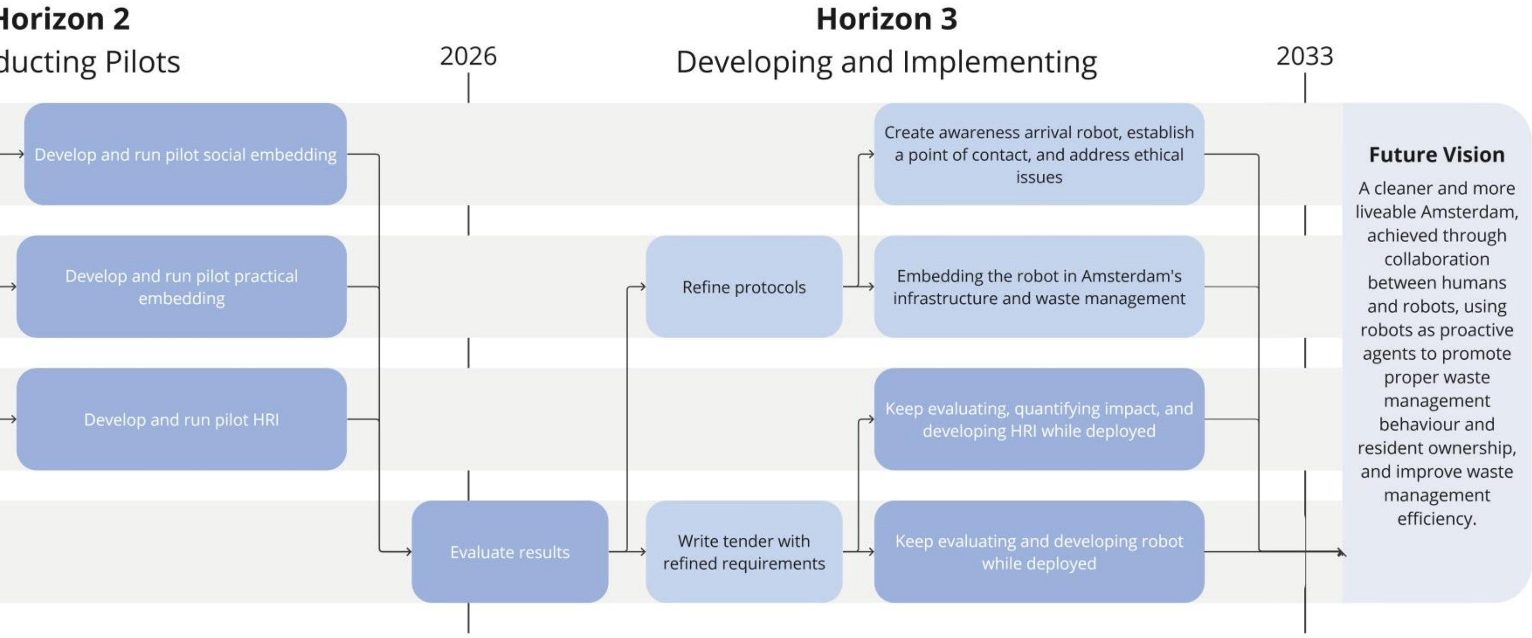


Figure 56. The roadmap provides a visual representation of the key activities required by the municipality of Amsterdam to realise the future vision of a cleaner city the collaboration of humans and robots. By outlining these activities, the roadmap serves as a communication tool to provide direction in the development of the proposed robots to achieve a cleaner Amsterdam

Horizon 1 Mapping Requirements

To ensure the long-term value of the robot for a cleaner Amsterdam, the project's initial phase focuses on identifying and mapping the requisite specifications for the robot's development. Given that numerous municipalities confront similar challenges in maintaining a clean urban environment, it may be worth exploring potential partnerships or collaborations with other Dutch municipalities first. Such an approach could be advantageous, given the high cost associated with robot development, and may enable access to more substantial resources. However, the unique characteristics and challenges of each municipality should be carefully considered to avoid potential complications when exploring partnerships for robot development.

To ensure that the needs and values of all stakeholders are met, and to build internal support for the use of robots as a tool to improve Amsterdam's cleanliness, a collaborative approach is needed, involving various stakeholders, including municipal parties and residents. By engaging stakeholders in the co-design of aspects such as the appearance and identity of the robot, their needs and values can be adequately addressed.



Moreover, the implementation of novel robotic solutions will lead to new situations and challenges that require attention to protect privacy and ensure the safety of individuals in Amsterdam. Therefore, it is essential to establish comprehensive protocols that address these new scenarios and any potential consequences resulting from the presence of the robot. For instance, it is crucial to address the potential risk of vandalism of the robot. These protocols will offer clear guidance to all parties involved in the implementation of the robots and help guarantee a seamless integration into Amsterdam's infrastructure and urban environment.

In addition, to further map the requirements of the robot in the field of human-robot interaction, in-depth research is essential to identify how the robot should navigate in a social environment and to determine the most effective strategies that can be employed in the HRI to promote proper waste management practices and enhance the relationship between humans and waste. By conducting this research, the project can establish a set of best practices that will guide the robot's behaviour. These practices are crucial to ensure that the robot contributes to the cleanliness of Amsterdam more effectively and successfully. Research institutions such as the AMS Institute, known for their comprehensive understanding of urban dynamics in Amsterdam, and technical universities such as the TU Delft can provide valuable resources for exploring and developing best practices in this area.

This phase will conclude with the establishment of a list of detailed requirements for the robots, covering various aspects of social and practical embedding, and HRI. These requirements will be utilised for testing and subsequent refinement in the following phase.

Horizon 2 Conducting Pilots

In order to enhance the likelihood of a successful implementation of the robots in Amsterdam, the second phase will emphasise the development of a comprehensive set of requirements that have been refined and evaluated through the implementation and evaluation of several pilots. This phase may involve collaboration with research institutions, other municipalities, and robotics companies to facilitate the prototyping, development, and execution of the pilots, leveraging their expertise and knowledge. The criteria for conducting the pilots will be derived from the list of requirements and details established in the previous phase, enabling their evaluation and refinement.

These pilots will cover several areas, such as the social aspect (i.e. examining the public's response in Amsterdam), practical considerations (i.e. evaluating how the robot will operate in Amsterdam), and human-robot interaction (i.e. determining the most effective strategies for the HRI). The outcomes of the pilots should be thoroughly evaluated with stakeholders, and necessary iterations should be made to refine the requirements for use in the next phase.

Horizon 3 Development and Implementation

The third phase will focus on directing the development of the robot to ensure a successful implementation. Initially, a tender will be drafted for the development of a robot by a robotics company, based on the refined requirements derived from the previous phase. It is crucial to continue evaluating the robots after their implementation in Amsterdam and to make necessary adjustments to accommodate unforeseen events. Through this on-going evaluation and adjustment process, a more successful implementation of the robots can be achieved.

Additionally, the protocols established in earlier phases should be thoroughly refined based on the evaluation of the pilot results. Furthermore, it is imperative that the robot is effectively integrated into Amsterdam's infrastructure and waste management systems. In this regard, the existing policies governing waste disposal in the city centre should be reviewed to establish the robotic container as a novel alternative waste disposal solution. Additionally, it is crucial for the municipality to consider incorporating the robot into future city infrastructure projects, including the planned hubs in Amsterdam. Such integration will help optimise the efficiency of waste flow and increase the value of the robot in achieving a cleaner city.

In order to facilitate a seamless transition and effective social integration of the innovative robotic solutions, it is necessary for the municipality to generate awareness among the people of Amsterdam, including residents, visitors and employees of the department Schoon, about the introduction of such robots. This can be achieved through awareness campaigns and open dialogues that emphasise the benefits of incorporating robots into the waste management practices. In these activities, the municipality should adopt a collective positive attitude towards the acceptance of the robot in order to prepare individuals for the arrival of these robots and to facilitate their acceptance, thereby contributing to the overall goal of achieving a cleaner Amsterdam.

Furthermore, to promote a greater social integration of robots, it is essential to proactively address potential privacy and safety concerns among the people of Amsterdam, including employees of the department Schoon. Such concerns have the potential to undermine the acceptance of robots and create a negative HRI. It is crucial for the municipality to establish a dedicated point of contact where individuals can express their concerns and receive reassurances regarding their privacy and safety.

Furthermore, it is important to address the fears that may arise among employees of the department Schoon regarding potential job replacement. This will help enhance the acceptance and adoption of robots within the department. Measures such as providing clear communication about the role of robots in enhancing human work can help alleviate such concerns.

Moreover, it is necessary to define clear guidelines that outline the responsibility for the actions of the robot. This will ensure transparency and accountability in its operation and address any potential issues that may arise.

By addressing privacy and safety concerns and promoting a positive perception of robot deployment, the municipality can enhance acceptance and prevent ethical issues and concerns from negatively impacting the integration of robots in Amsterdam.

To ensure that the robots are well adapted to the specific needs and requirements of Amsterdam, a crucial aspect of the implementation of the Mobile Robot Bin and Mobile Robot Container concepts in Amsterdam is evaluation, e.g. by quantifying the impact of the HRI, and continuous development of the robots. Incorporating iterative improvements to the robots is essential to achieve the future vision of a cleaner Amsterdam through the collaborative efforts of people and robots. This adaptive approach will ensure that the robots are continuously optimised to meet the specific needs and requirements of the city, leading to more successful waste management outcomes.

9.3 Conclusion Implementation Strategy Roadmap

In conclusion, the evaluation process involving stakeholders from the municipality of Amsterdam and the department Schoon showed a common recognition of the potential and value of deploying the Mobile Robot Container and the Mobile Robot Bin in Amsterdam. While the stakeholders unanimously agreed that the Mobile Robot Container would have the greatest added value, both robots were included in the roadmap.

The roadmap developed in this chapter serves as a tool to effectively communicate the necessary activities that the municipality of Amsterdam must undertake to successfully implement the robotic solutions to achieve a cleaner city. The roadmap focuses on four key elements: Social Embedding, Practical Embedding, Human-Robot Interaction and Development. By addressing these elements, the city will be able to more effectively manage the complexities involved in developing and deploying the robots and ensure a more successful integration in Amsterdam.

The roadmap is divided into three horizons: Mapping Requirements, Conducting Pilots, and Development and Implementation. The first horizon focuses on identifying and mapping the necessary specifications for robot development, engaging stakeholders, establishing protocols and conducting in-depth research on HRI. The second horizon focuses on conducting pilots to refine and evaluate the requirements, taking into account social aspects, practical considerations and HRI. The third horizon focuses on managing the development and implementation of the robots, refining the protocols, integrating the robots into Amsterdam's infrastructure, raising awareness and addressing ethical issues and concerns.

Continuous evaluation and development is essential throughout the implementation process to ensure that the robots are well adapted to the needs and requirements of Amsterdam. Iterative improvements will be necessary to meet the specifications and effectively achieve a cleaner city through the combined efforts of humans and robots.

This roadmap was shown to and validated with the AMS Institute expert (see Chapter 8.3), who had no further comments or additions.

10

Discussion and Recommendations

10 Discussion and Recommendations

Faced with the challenge of keeping the city clean, which affects the quality of life of its residents, Amsterdam requested to explore the potential value of robots as an additional resource. Consequently, the aim of this thesis is to provide an initial exploration of how robots can be of value in contributing to a cleaner, and therefore more liveable, Amsterdam. Chapter 10.1 discusses the findings of this thesis in detail and provides insights into the potential contributions of robots in addressing the city's cleanliness issues. Chapter 10.2 provides a conclusion of this thesis and Chapter 10.3 identifies the limitations encountered during the research process and provides recommendations for future research. Finally, Chapter 10.4 presents the author's personal reflection on this thesis.

10.1 Discussion

This thesis provides insight into the research question of how a robot can contribute to a cleaner and more liveable Amsterdam in the long term. In summary, the answer to the research question is that the robot should be able to involve individuals in waste management practices, promoting responsible waste behaviour and a sense of ownership to avoid stimulating littering behaviour. At the same time, the robot should improve the efficiency of Amsterdam's waste management processes in order to tackle waste problems more effectively. To answer the research question, the complex and evolving nature of the context, the city of Amsterdam, involving multiple stakeholders with different needs, values and behaviours, was explored and described below.

In order to explore the origins of the waste challenges in the context of Amsterdam, this thesis carried out a waste analysis that identified three common waste challenges in Amsterdam. It should be acknowledged, however, that there may be other challenges as well, and this thesis focused primarily on the city centre, as this is the most affected area in Amsterdam. The analysis also showed that human littering behaviour is a major contributor to the waste challenges. In order to understand this behaviour, the key factors influencing littering behaviour were examined and it was found that inefficiencies in Amsterdam's waste management system could potentially encourage littering behaviour. Therefore, it was concluded that a robot capable of both improving waste management efficiency and promoting proper waste management behaviour would be of significant value in contributing to a cleaner Amsterdam.

Another finding of this thesis was that the use of an autonomous cleaning robot could potentially encourage littering behaviour and thus contribute to a dirtier Amsterdam over time. As a result, a robot tasked with autonomous cleaning in Amsterdam is considered undesirable. However, it is important to emphasise that this finding is based on a hypothetical exploration using key factors of waste management behaviour found in the literature. It is possible that a cleaning robot could be designed to encourage responsible behaviour. However, it is important to understand that the mere presence of a cleaning robot could potentially motivate littering behaviour, as the presence of cleaners was identified as a significant key factor in motivating littering behaviour.

In addition, the HRI research showed that robots can play a role in creating a cleaner environment without being directly involved in cleaning activities. As a result, a design vision was developed in which a robot can contribute to a cleaner Amsterdam by optimising waste management efficiency, promoting proper waste management behaviour and fostering a sense of ownership among residents.

This design vision already provided an answer to the research question. However, in order to effectively communicate this vision to stakeholders in a more tangible way, this thesis proposed two different robotic concepts, each designed with its own set of objectives, taking into account the different sources of waste problems identified in the city. The first concept, called the Mobile Robot Bin, aims to address littering behaviour by creating a rewarding HRI to actively involve individuals in the waste disposal process. However, it is important to note that the Mobile Robot Bin HRI design is preliminary and further research is needed to determine the most optimal HRI approach to encourage proper waste management behaviour. Recommendations on this topic can be found in Chapter 10.3.

The second concept, the Mobile Robot Container, aims to provide waste disposal options at will for residents in the city centre, optimise the efficiency of waste management and promote proper waste management behaviour by encouraging responsibility and ownership among residents in order to contribute to a cleaner environment in Amsterdam. However, as this concept aims to transport waste using Amsterdam's infrastructure, it is important to recognise that the implementation of this concept may face feasibility challenges due to the complexities associated with achieving autonomy and autonomous driving within a decade in Amsterdam's complex urban environment. Chapter 10.3 provides recommendations on this issue.

Both concepts were evaluated with stakeholders from the municipality of Amsterdam, the department Schoon and the AMS Institute and received positive and enthusiastic feedback as they saw their potential to contribute to a cleaner Amsterdam. It should be emphasised, however, that the Mobile Robot Container concept was unanimously selected as the one with the greatest feasibility and added value in achieving a cleaner Amsterdam. Throughout the evaluation process, challenges were identified for both robot concepts, such as vandalism. These challenges require further research and are addressed in the recommendations in Chapter 10.3.

During the feedback session with the municipality of Amsterdam and the department Schoon, they expressed interest in the subsequent development steps necessary to deploy the proposed robots. As a result, a roadmap was developed to outline the activities required for implementation. During the feedback session with the representative of the AMS Institute, recommendations for implementation activities were made. Consequently, it was considered valuable to present the roadmap that had already been developed, as the recommendations given had already been incorporated into the roadmap. The expert agreed with the content of the roadmap and did not make any additional comments or recommendations.

While it is true that the evaluation process involved a limited number of representatives from the municipality of Amsterdam, the department Schoon and the AMS Institute, it is important to recognise the expertise and knowledge of these individuals. Despite the small sample size, their extensive experience in their respective fields enabled them to provide valuable insights and feedback on the proposed concepts. Nonetheless, it is recommended to consider expanding the scope of the evaluation process in future assessments to ensure a broader representation and diversity of perspectives.

It should be noted that the roadmap developed in this thesis used a customised methodology. Traditional roadmap methodologies typically focus on the business context, encompassing factors such as market segmentation and existing products and services. As the purpose of the roadmap for this thesis was to effectively communicate the activities required to deliver a completely new robotic 'service' to the municipality, which they will not be developing themselves, elements of conventional methodologies become less applicable in this particular context, making these commonly used methodologies not well suited to this objective. Therefore, an alternative approach to the roadmap was adopted. This approach focused on communicating the essential activities in different areas that were deemed necessary to provide the municipality with a clearer overview to better manage the complexities involved in robot development and to facilitate a more successful deployment of robots that can contribute to a cleaner Amsterdam.

10.2 Conclusion

In conclusion, as Amsterdam is currently unable to meet its cleanliness targets, this thesis aims to provide insight into how robots can contribute to a cleaner and more liveable Amsterdam. As the city grows, combined with increased tourism and the city's sustainability goals, these waste-related challenges will increase and the need for more efficient waste management practices in Amsterdam will grow. However, challenges such as labour shortages and demographic ageing make it difficult to rely solely on additional human labour. In response to these challenges, the municipality of Amsterdam is actively exploring innovative waste management strategies, including the use of innovative technologies, and the promotion of resident ownership to encourage proper waste management behaviours. A robotic solution could be valuable in addressing these growing challenges in Amsterdam by optimising the efficiency of waste management and increasing capacity while reducing the need for additional human labour. In addition, several developments arising from Amsterdam's future vision offer opportunities, such as the establishment of car-free zones and transport hubs, as they create space and opportunities for the integration of robots with alternative modes of transport.

In order to gain a better understanding of the capabilities of robots in a decade's time, in order to design a robot in this thesis, a literature review was conducted. This revealed that on-going advances in machine learning, connectivity and autonomous driving technologies are increasing the capabilities of robots, offering promising opportunities for robot deployment in Amsterdam. The decreasing costs of AI training and hardware components further improve the economic feasibility of implementing robots in the near future. However, it is important to recognise that despite these technological advances, navigating unpredictable urban environments remains a significant challenge the coming years.

Furthermore, as the robot is likely to be deployed in the department Schoon, values were identified that are crucial to ensure continued job satisfaction in order to promote a more successful implementation of robots in the department. In collaboration with a fellow graduate student, six key values were identified by accompanying and interviewing employees in the Amsterdam cleaning department, department Schoon. These include freedom, variety, working outdoors, social interaction, dislike of heavy work and tangible results. The research also highlighted the challenges faced by the department, including communication difficulties, labour shortages, reduced efficiency and complex traffic situations.

In order to understand how the robot's task could contribute to a cleaner Amsterdam, the city's waste problems were analysed. Insights gained from accompanying the employees, combined with an analysis of relevant documents on waste issues in Amsterdam, led to the identification of three main waste problems: waste bags on the streets in the city centre, waste found next to containers and litter in the environment. An in-depth study of these problems was carried out to determine where a robot could add value. A key finding was that these problems were often caused by inefficient waste management practices and inappropriate waste management behaviour by individuals.

In addition, in order to understand complex waste management behaviour of individuals, key influencing factors were identified and used to gain a deeper understanding of the origins and causes of Amsterdam's waste problems in terms of littering behaviour. As littering behaviour is a major contributor to these waste problems, in addition to waste management inefficiencies, it became clear in this thesis that the role of a robot should not only focus on improving waste management efficiency, but also on reducing littering behaviour in order to maximise its impact on creating a cleaner Amsterdam.

Furthermore, to ensure the successful implementation and acceptance of robots in Amsterdam, several key factors influencing HRI were identified by conducting a literature review. These can be categorised into two clusters: the first cluster consists of factors that increase HRI when these factors increase, such as perceived usability, usefulness and subjective social norms, and the second cluster includes factors that need to be adapted to the needs and roles of the specific situation. These factors include perceived humaneness, social interactivity, social presence, sense of safety and comfort, and perception of pleasantness.

Moreover, to explore how the key factors of HRI are currently being used in robots in the context of waste management, an exploration was carried out. This showed that these factors can be used to encourage appropriate waste management behaviour by creating rewarding interactions. This can be achieved, for example, by incorporating movement or verbal cues into the robot's functions. This finding implies that through effective HRI, individuals can be motivated to actively participate and take responsibility for the waste management process. It is concluded that robots can contribute to a cleaner Amsterdam without necessarily performing the physical act of cleaning the environment themselves.

In addition, to explore the value of an autonomous cleaning robot in contributing to a cleaner Amsterdam, key factors of waste management behaviour were used to explore the potential impact on this behaviour. This revealed the potential unintended consequences, as the robot could potentially trigger motivators for littering behaviour in individuals, such as a perceived reduction in personal responsibility for waste management, as individuals may rely on the robot to clean up after them. This highlights a potential relationship between robots, waste and humans. The robot's task in relation to waste and its interaction with people may influence people's relationship with waste and their subsequent behaviour, as these are closely linked.

In order to shape and guide this thesis based on all the findings to answer the research question, specific requirements were established and a concrete design vision for the robot was developed. The vision emphasised the role of the robot in promoting correct waste management behaviour, cultivating a sense of responsibility for waste management and increasing waste management efficiency. By incorporating these principles into the design of the robot, the aim is to contribute to a cleaner Amsterdam while mitigating any unintended negative effects on waste management behaviour and people's overall relationship with waste that may result from the deployment of the robot.

To effectively communicate the vision to the municipality, two robotic concepts, the Mobile Robot Bin and the Mobile Robot Container, were developed to provide a tangible demonstration of how robots can contribute to a cleaner Amsterdam. The Mobile Robot Bin aims to tackle the problem of littering by motivating proper waste management behaviour through a rewarding interaction to disrupt littering habits. This interaction aims to encourage people to take personal responsibility for the proper disposal of their waste. In order to fit in with Amsterdam's identity, it is proposed to create the appearance in collaboration with local artists, as well as to raise public awareness and promote a sense of ownership among residents. In addition to addressing littering behaviour, the robot aims to provide an efficient waste collection process that optimises the waste flow.

The Mobile Robot Container concept aims to provide residents with waste disposal options at will in the city centre, to optimise waste management efficiency and to promote proper waste management behaviour by encouraging responsibility and ownership among residents, thereby contributing to a cleaner environment in Amsterdam. By allowing residents to deposit their waste inside the robot, it aims to reduce littering behaviour, particularly in light of the current policy of allowing residents to deposit waste bags on the street twice a week, which this thesis has shown to lead to waste accumulation and encourage littering. With its autonomous waste transfer capabilities, the robot optimises waste flow and waste management efficiency. The robot also reduces the physical burden on staff by eliminating the need to pick up bags from the street and minimises the need for heavy waste trucks in the city centre.

In order to assess the added value of the proposed concepts in tackling the waste challenges for a cleaner Amsterdam and to ensure compatibility with the city, stakeholders from the municipality of Amsterdam and the department Schoon were involved in an evaluation session. In addition, an expert from the AMS Institute was consulted to assess the feasibility. Based on the feedback and discussions, both concepts received enthusiastic responses, but the Mobile Robot Container was identified as the most promising concept to achieve a cleaner Amsterdam. However, challenges such as vandalism and legal barriers need to be addressed before implementation. Suggestions were made to explore options such as self-emptying the robot into a boat or integrating the robot into the Roboat project. The stakeholders were enthusiastic and asked questions about the next development steps, agreeing on the importance of personal responsibility in waste management when using robotic solutions. However, in order to make the best possible contribution to a cleaner Amsterdam, more research is needed to develop and deploy the most optimal robotic solutions.

In order to provide the municipality with a clearer overview to better manage the complexities involved in robot development and to facilitate a more successful deployment of robots that can contribute to a cleaner Amsterdam, a roadmap was developed. To ensure that the roadmap included the necessary activities, it was validated with an expert from the AMS Institute. The roadmap focuses on four key elements in which activities are needed: Social Embedding, Practical Embedding, Human-Robot Interaction and Development. The roadmap is divided into three horizons: Mapping Requirements, Conducting Pilots, and Development and Implementation. The first horizon focuses on identifying and mapping the necessary specifications, the second horizon focuses on conducting pilots to refine and evaluate the requirements, and the third horizon focuses on managing the development and implementation of the robots, where continuous evaluation and development is essential to ensure that the robots are better adapted to the needs and requirements of Amsterdam.

10.3 Recommendations

The primary objective of this thesis was to provide an initial exploration of how robots can contribute to a cleaner and more liveable Amsterdam. Given the prescribed time frame of 20 weeks for this thesis, it was imperative to establish a specific scope that would enable the research question to be effectively addressed within the limited time frame. Although this thesis has undertaken a thorough exploration of the research question, it is important to acknowledge that certain areas were not explored extensively due to time constraints. As a result, some aspects that are critical to the future development and use of robots were not addressed in depth in this preliminary exploration. However, given their importance, further research in these areas is necessary to ensure a successful implementation of robots in Amsterdam. The following sections outline the limitations that require further investigation beyond the scope of this thesis.

Costs Analysis

The cost challenge has already been addressed to some extent in the proposed concepts. However, an accurate estimation of the associated costs for the proposed robots remains difficult at this stage due to the unavailability of the necessary information to determine the costs. Several factors are likely to influence these costs, and further research into these factors during the subsequent phases of robot development would enable a more accurate assessment of the financial implications for the municipality of Amsterdam. This may not be an all-encompassing list, but some of the factors that influence the costs include:

- The number of robots required, which can be determined by carrying out an analysis to determine the optimal deployment of the robots. For the Mobile Robot Containers, factors such as the number required per neighbourhood to provide the most value and finding the right balance between active robots and those stationed at hubs, charging and waiting to be used, need to be considered. Similarly, for the Mobile Robot Bin, the most effective deployment strategy to minimise the littering behaviour of individuals needs to be determined to identify the required number of robots.
- The complexity of the robot's functionality, as more components increase the cost. Conversely, reducing the number of components used in a robot results in a more cost-effective solution.
- The operating range of the robots, which depends on the battery capacity.
- The potential for collaboration with external organisations or municipalities to share the financial burden.
- The effectiveness of robots in optimising waste management practices, potentially reducing the need for existing services.

Feasibility of Robot Implementation

Despite the efforts made in this thesis to address the feasibility limitations and improve the practicality of deploying robots within a 10-year timeframe, accurate prediction of the development trajectory of robotic capabilities and autonomous driving technology remains uncertain. These technical limitations have a significant impact on the feasibility of robot deployment in the coming decade. It is therefore crucial that further research is conducted during the robot development phase to proactively address these factors. By doing so, a better understanding can be gained and appropriate measures can be taken to overcome potential challenges and ensure the successful integration of robots within the intended timeframe.

Furthermore, it is crucial to consider the current urban regulations, as these can have a significant impact on the feasibility of robot deployment. It is likely that modifications to existing regulations will be required to facilitate the seamless integration of robots into traffic and other urban environments. By identifying and addressing these regulatory issues through research and analysis, Amsterdam can address potential challenges and ensure a more successful integration of robots into the city's urban environment.

In addition, the challenge of electric charging is another factor that can affect the feasibility of robot implementation. As highlighted in the feedback session in chapter 8.2, the department Schoon is already experiencing difficulties with charging their electric vehicles. However, with the city of Amsterdam aiming to only allow electric vehicles on the A10 inner ring road by 2030 (RTL Nieuws, 2022), and the growing number of electric vehicles in the Netherlands, the demand for charging infrastructure will increase (Planbureau voor de Leefomgeving, 2022), which will require efforts to ensure an effective charging network. Therefore, addressing the issue of the required electric charging infrastructure is not only essential for the implementation of robots, but also for the wider transition to electric vehicles in the city. By proactively addressing this challenge, Amsterdam can facilitate a more successful integration of robots while supporting the broader goal of transitioning to a sustainable electric vehicle-based future. In addition, exploring alternative solutions, such as equipping the robots with solar panels for recharging, could be a viable option if the challenge of establishing an extensive recharging infrastructure proves too challenging.

Human-Robot Interaction

In this thesis, a detailed investigation of the factors influencing the HRI has been carried out, with an emphasis on their practical application in the design of the robots. However, further refinement is required, particularly in relation promoting proper waste management behaviour in the interaction, specifically in regards to the Mobile Robot Bin. In order to effectively promote correct waste management behaviour through interaction, a more extensive research in this area is required.

This presents an interesting research opportunity that could be pursued, for example, as a graduation project for a Design for Interaction masters student at the TU Delft. The aim would be to investigate and establish the optimal HRI to effectively stimulate proper waste management practices in the unique context of Amsterdam. To evaluate specific aspects of the robot's behaviour and its impact on motivating proper waste management behaviour, a possible test environment could be to deploy a prototype of the robot in a busy public square in Amsterdam, such as Dam Square. This setup would allow for careful observation and evaluation of the reactions elicited, providing valuable insights to further improve the HRI.

It is crucial to consider the presence of a significant number of tourists, who bring with them their own waste management behaviours, which may differ from local practices, and their relatively short stay in the city may present challenges in effectively influencing their behaviour through HRI. These aspects should be included in further research to develop appropriate HRI strategies for different user groups.

Ethical considerations are also of significant importance in the development of a successful HRI and will be examined in more detail below. In addition, the interaction of robots with traffic requires careful consideration to ensure safe navigation. Mutual understanding and clear signalling of the robot's intentions are essential to prevent accidents.

By addressing these issues, the research can contribute to a comprehensive understanding of HRI in promoting appropriate waste management behaviours. Ultimately, this will enable a more seamless integration of robots into Amsterdam's urban environment, optimising waste management practices and improving the overall HRI experience for both residents and visitors.

Ethical Issues
The introduction of robots in Amsterdam will create new situations and potential ethical issues that require attention, particularly in terms of safety and privacy. Although certain ethical issues have already been identified and incorporated into the roadmap outlined in Chapter 9, such as establishing accountability for robot actions, it is crucial to conduct further in-depth research to fully understand and address the range of ethical concerns that may arise with the implementation of robots in Amsterdam. By doing so, the city can better anticipate and mitigate potential ethical issues and ensure a more successful integration of robots while meeting ethical requirements.

Vandalism
Furthermore, vandalism of the robots was identified by the stakeholders as a significant challenge. Given the limited presence of robots in public spaces, they may attract attention and become targets of vandalism. (Zlotowski et al., 2015) In order to proactively address this challenge and to ensure the successful integration of robots into the urban environment, while minimising the risk of damage or disruption to their operations, it is essential to conduct comprehensive research and implement appropriate measures. Potential approaches include:

- Design robots with a robust and vandal-resistant physical form suitable for deployment in public spaces. This design should prioritise durability and the ability to withstand potential acts of vandalism.
- Investigate strategies to influence human behaviour to discourage vandalism of robots. One approach could be an extended phase-in period, during which the robots are gradually introduced to the public, allowing people to become familiar with their presence and purpose.
- Promote ownership and responsibility for the robots by emphasising the benefits and importance of their functions, as well as the cost and effort involved in their deployment, to develop a collective sense of protection and discourage acts of vandalism in the community.
- Take preventive measures to prevent unauthorised removal of the robots. For example, in the case of the Mobile Robot Bin, an alarm system can be incorporated or another possible solution would be to secure the robots overnight in designated stations located in their assigned areas. These stations would provide a secure environment for the robots and could also act as charging stations.

10.4 Personal Reflection
This project was both enjoyable and intense, with significant challenges, especially given the hypothetical and futuristic aspect of the project, as it involved an initial exploration of the potential value of robots in achieving a cleaner Amsterdam. The complexity of the project, due to the many interrelated components and involved stakeholders, made it difficult to turn it into something tangible that would benefit Amsterdam. Nevertheless, I am satisfied with the result, because I think it is a

meaningful contribution that could guide the municipality in its next steps to develop robots that can contribute to a cleaner Amsterdam.

One of the most important learning experiences I had during this project was the ability to make decisions independently. In the beginning, this was a major challenge for me, which my mentors also repeatedly pointed out, given the complexity and uncertainties inherent in the project. As the project progressed, I gained a sense of improved proficiency in this regard. It is interesting to note that I was initially unaware of the challenging aspect of decision making, as my academic education was mainly based on collaboration, with opportunities to evaluate choices through collective discussions. Now, however, I have learned to rely more on myself when it comes to decision-making in projects. This will undoubtedly prove valuable in my future endeavours as an industrial designer.

This project would not have been possible without the critical mindset I acquired during my Master in Strategic Product Design (SPD) at TU Delft. During my education I was taught to first understand the exact problem and to question whether the proposed solution is really the right one. For example, when I engaged in discussions with various individuals, their common suggestion was to develop a cleaning robot to improve the cleanliness Amsterdam. However, thanks to the learned critical mindset, I saw the need to question the validity of this solution for achieving a cleaner Amsterdam on the long term. Through my research, I discovered the important role of waste management behaviour in the city's dirtiness and identified the main factors influencing it. When evaluating the potential effect of an autonomous cleaning robot in relation to these key factors, I found that such a robot could unintentionally contribute to, for example, a decrease in individual perceived responsibility for their own waste, thereby stimulating littering behaviour. This confirmed my intuition, which had been strongly influenced by my education, and based on these insights, I formulated a vision where individuals remain actively involved in the waste disposal, leveraging robots as tools to encourage responsible waste management behaviour. By combining this approach with the enhancement of waste management efficiency, robots can provide the greatest long-term value in achieving a cleaner Amsterdam.

Therefore, the critical mindset instilled in me during my academic journey, particularly during my Master's in SPD, played a pivotal role in shaping the vision and direction of this project. It enabled me to challenge conventional assumptions, uncover key insights, and develop a solution that aligns with the long-term goals of achieving a cleaner Amsterdam.

In addition, the SPD Master has given me the necessary skills to extract valuable insights from a variety of complex factors, including developments and stakeholder needs. These skills were essential in successfully navigating the complexities involved in this project and synthesising them into a coherent and impactful outcome.

While this project may deviate from the conventional SPD framework, which typically focuses on commercial business contexts and the development of products or services for that context, it remains true to the core purpose of SPD. In my perspective, the core objective of SPD is to translate the multitude of stakeholder needs and values, developments and opportunities within a given context into a strategic solution that contributes to a long-term goal. In this thesis, the above elements have been carefully considered within the unique context of Amsterdam to formulate a strategic design characterised by a thoughtful consideration of its intended function and aimed at maximising its effectiveness and long-term impact on achieving a cleaner Amsterdam.

This aligns seamlessly with the essence of SPD, which aims to "maximise the impact of design on business and markets." (TU Delft, n.d.) In the case of this thesis, the municipality and the city of Amsterdam serve as the "business and market," given that the robot is designed specifically for this context. The core focus of my “design” is to maximise its impact, taking into account various aspects of the context, including key factors of littering behaviour and the underlying origins of waste challenges in Amsterdam. By incorporating these considerations, the design aims to contribute to Amsterdam's goal of achieving a cleaner city if they were to use these proposed robots in their waste management practices.

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Appendices

Appendix A Key Factors Littering Behaviour

The four clusters of factors influencing littering behaviour will be explained in detail next.

Personal Factors

Personal factors refer to individual influences and characteristics that influence whether a person exhibits littering behaviour. These factors are grouped into the clusters of ownership, consciousness, attitude and values and affect and emotion.

Ownership

The perceived personal responsibility, either for one's own waste or for the environment, is a key factor influencing litter behaviour. The feeling of responsibility can be influenced by how someone feels about a particular place; the less responsible one feels about a place, the more likely one is to litter. (Campbell, 2007) Several studies have pointed out that the feeling of being responsible often decreases when a person believes a space is being cleaned; it is seen as a more acceptable place to litter. (Lewis et al., 2009) Moreover, the visible presence of cleaners in a particular place can reinforce that sense that a place is being cleaned. (Lyndhurst, 2012)

The feeling of being connected to others or to a place, in other words a sense of community, is another factor that reduces littering behaviour, while a lack of sense of community can increase littering behaviour by 10%. (Lyndhurst, 2012)

A sense of respect for other people or a local area is another influencing factor; the extent of this feeling determines whether it is a motivator for proper or improper waste disposal behaviour. (Campbell, 2007; Keep America Beautiful, 2007; Lewis et al., 2009)

Factors such as taking pride or having a sense of ownership for a local place are also motivators for showing proper litter disposal behaviour. (Campbell, 2007)

The desire to do the correct thing is also a strong behavioural motivator for proper waste disposal. (Lyndhurst, 2012)

Consciousness

Being consciousness about waste is another key influencing factor and it can be explained in different ways; it may be knowledge of the consequences of litter or the perception of what qualifies as litter. Lack of knowledge about the impact of litter can lead to a belief that littering is not an important problem, forming a barrier for someone to show the desired waste disposal behaviour. (Lyndhurst, 2012)

Cigarette butts and biodegradable or small items are often perceived as things that do not qualify as litter, making people more likely to dispose of such items improperly because they think the consequences will be minimal. (Lyndhurst, 2012)

Attitude and Values

Someone's personal norms and values are also key factors of influence on littering behaviour; when these norms and values are opposed to littering, it acts as a motivator for exhibiting correct waste disposal behaviour and vice versa. One study pointed out that by activating someone's personal norm, by directing one's attention to their behaviour, littering behaviour can be reduced significantly. (de Kort et al., 2008)

A person's attitude is another influencing factor; for example, someone with a more individualistic attitude will be more likely to exhibit littering behaviour. (Lyndhurst, 2012)

Other key drivers of littering behaviour are laziness (Lyndhurst, 2012; Texas Disposal Systems, 2023) and the perception of the dirtiness of an object someone wants to throw away; the dirtier, the greater the aversion to holding on to the waste and the desire to get rid of it as quickly as possible. The perception of the available bins also plays a role; the dislike of bins can reduce the probability that someone will properly throw something away. (Lyndhurst 2012)

Affect and Emotion

The literature suggests that emotions such as guilt or fear may play a role in litter behaviour. The effect of these emotions, however, is a contradiction in the literature; some studies indicate that feeling guilty about littering reduces litter behaviour, while other studies show that guilt does not prevent people from littering. (Lyndhurst, 2012) The latter study implied that people make up excuses for their behaviour instead of avoiding the behaviour that caused guilt in the first place. (Campbell, 2007) Another study indicated that fear of the health effects of litter may encourage proper litter disposal. (Alice Ferguson Foundation, 2011) Altogether, this suggests that the role of emotions in littering behaviour is not yet fully understood.

Social Factors

Social factors refer to "*the influence on our thinking and behaviour from the wider social context*," (Lyndhurst, 2012) which includes social norms and networks.

Social Norms

The social context a person is in is a strong factor in littering behaviour. Here a distinction can be made between what others do (descriptive norms) and what should be done (injunctive norms). Regarding the former, the perceived behaviour of others is of importance, as well as the amount of litter in an area, since that also indicates how people behave.(Lyndhurst, 2012) When someone has the feeling others are littering as well, it can feel as "permission" to exhibit the same behaviour, making people more inclined to litter in a dirtier environment. One study indicated that messages that show descriptive norms are counterproductive when it contradicts the actual visible behaviours of others in a given area, resulting in increased amounts of litter. (Cialdini, 1990) This is partly why it is suggested that pointing out what should be done is more effective, since it draws attention to the social impact of litter and avoids a possible contradiction.

Social Networks

The presence of others is another influencing factor, as people tend to adopt the behaviour of others around them to avoid social rejection. Furthermore, a person's social network is a strong factor influencing their willingness to dispose waste in an improper way; if someone close to them disapproves of littering behaviour, people will be less inclined to show that behaviour. (Straughan et al., 2011) Similarly, the absence of a sense of social disapproval of littering can act as a motivator for that behaviour. One's upbringing and the examples one has received of how others deal with waste are also factors of influence. (Campbell, 2007)

Habitual Factors

Habits are included in this framework as these types of unconscious behaviours are expected to influence whether a person exhibits littering behaviour. Habitual factors, *"refer to patterns of behaviour which individuals carry out almost automatically; in other words, unconscious drivers of behaviour which result from becoming 'locked in' to certain patterns."* (Lyndhurst, 2012)

Occasionally, littering behaviour can arise out of a cognitive shortcut, a bad habit, and this behaviour can be subconscious, something a person might not even think about when littering. Disrupting bad habits through interventions or triggers can be a way to draw attention to this bad behaviour patterns in order to address the problem. (Huffman et al., 1995)

Material Factors

The material factors refer to "*the context in which behaviours are formulated and acted out, which can enable or constrain particular kinds of behaviour. It can include, for example, services, infrastructure and technologies."* (Lyndhurst, 2012) The key factors are access to bins, appearance of a place and enforcement.

Access to Bins

Insufficient or no access to trash bins can enhance the feeling that littering behaviour is acceptable. (Texas Disposal Systems, 2023) Similarly, when a bin is overflowing, many seem to find it acceptable to throw their trash next to it. (Williams, et al., 1997) The observed state of a trash can is also a factor that influences whether someone will use it; if it is dirty, people tend to use it less. (Lyndhurst, 2012)

Several studies have found that the majority of littering happens within 5 metres of a trash can (Williams, et al., 1997; Victorian Litter Action Alliance, 2014), and no correlation could be found between the likelihood of someone littering and the amount of trash cans. (Lyndhurst, 2012) It was also observed that many people do not really bother to look for a trash can and prefer to throw their trash on the ground. All in all, it was concluded that placing more trash cans or emptying the bins more frequently will have little impact on reducing littering behaviour. (Campbell, 2007)

Appearance of a place

The cleanliness of a place is another factor that plays a role in littering behaviour; people tend to litter more in a dirty or degraded environment than in a clean area. (Lyndhurst, 2012; Ministerie van Infrastructuur en Waterstaat, n.d.-c) The presence of litter may give a sense that it does not matter if someone throws an extra item on the ground, thereby increasing littering behaviour. However, the litter does not necessarily have to be visible, a study showed, because people may justify their littering behaviour if they know there was litter in a certain place before. (Williams, et al., 1997)

In addition, a person's feeling about a place also influences littering behaviour. One is the feeling of responsibility for a place, which, as mentioned earlier, decreases when people think a place is being cleaned or when cleaners are visible. (Campbell, 2007) Also, the feeling of being anonymous in a particular place influences and enhances littering behaviour. (Lyndhurst, 2012; Ministerie van Infrastructuur en Waterstaat, n.d.-c)

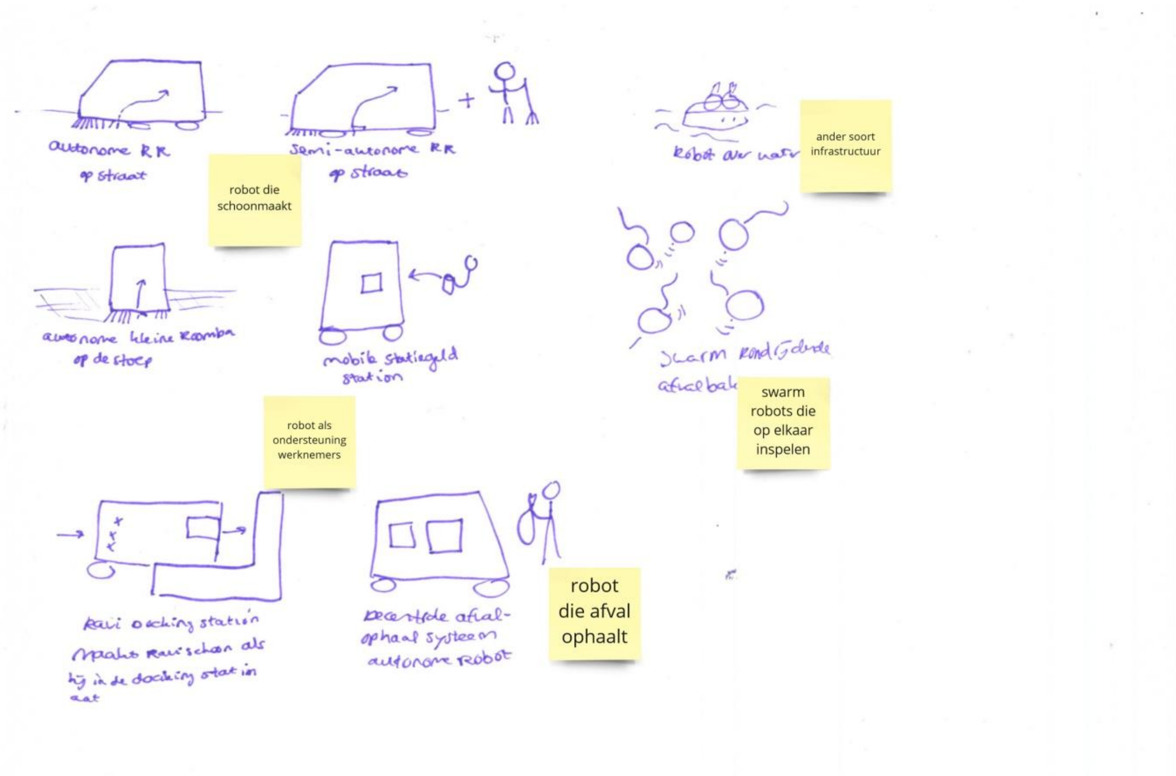
Enforcement

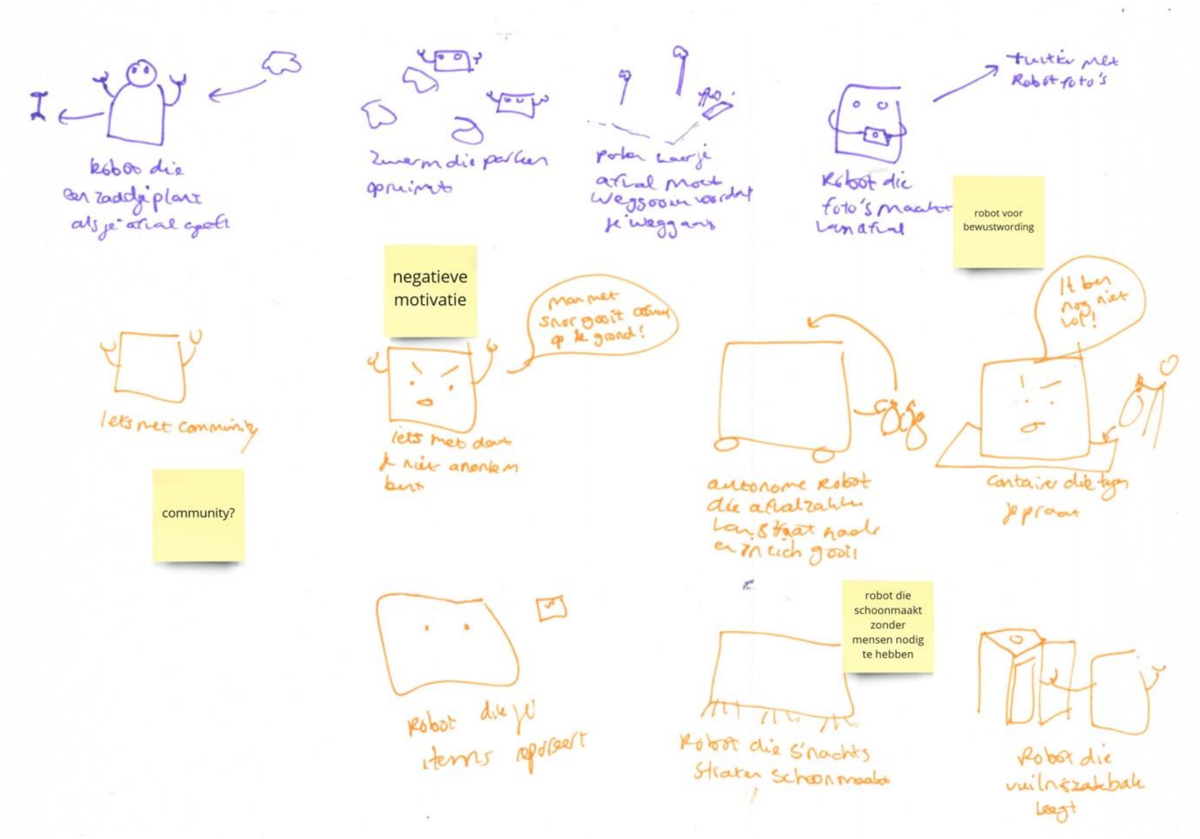
Enforcement measures, such as fines, can be a motivation to properly dispose of waste. (Campbell, 2007) However, there are some credibility issues with these measures, as many do not believe they will be fined. One study even suspected that a polluter's underlying values do not change after a fine and that this may mean he or she will be more careful when littering next time. (Lyndhurst, 2012)

Appendix B Brainstorm Session 1

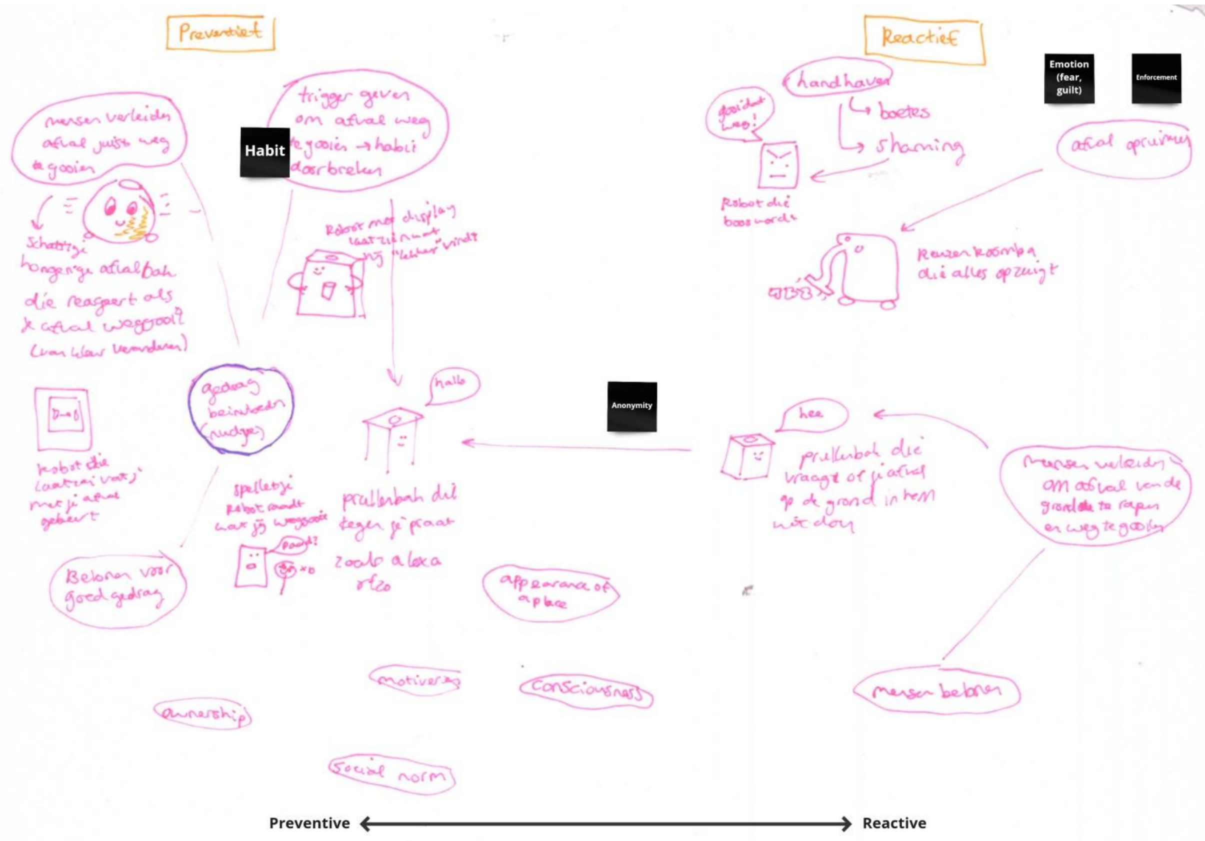
negatieve effecten van acties laten zien
positieve effecten van acties laten zien
informeren
positieve beelden
recycle
belonen
met geld
bewust worden groter geheel
motiveren
afval weggooien leuk maken
afval knutselhoek
afvalmuseum
museum of trash
positieve feedback
inspelen op emotie
Hoe kan de robot de relatie die mensen hebben met afval verbeteren
meer zelf doen
bewustmaking: jouw acties hebben effect
positieve herinneringen aan afval geven
'broken window' effect: schone straat --> goed gedrag
bewust maken dat iets afval is

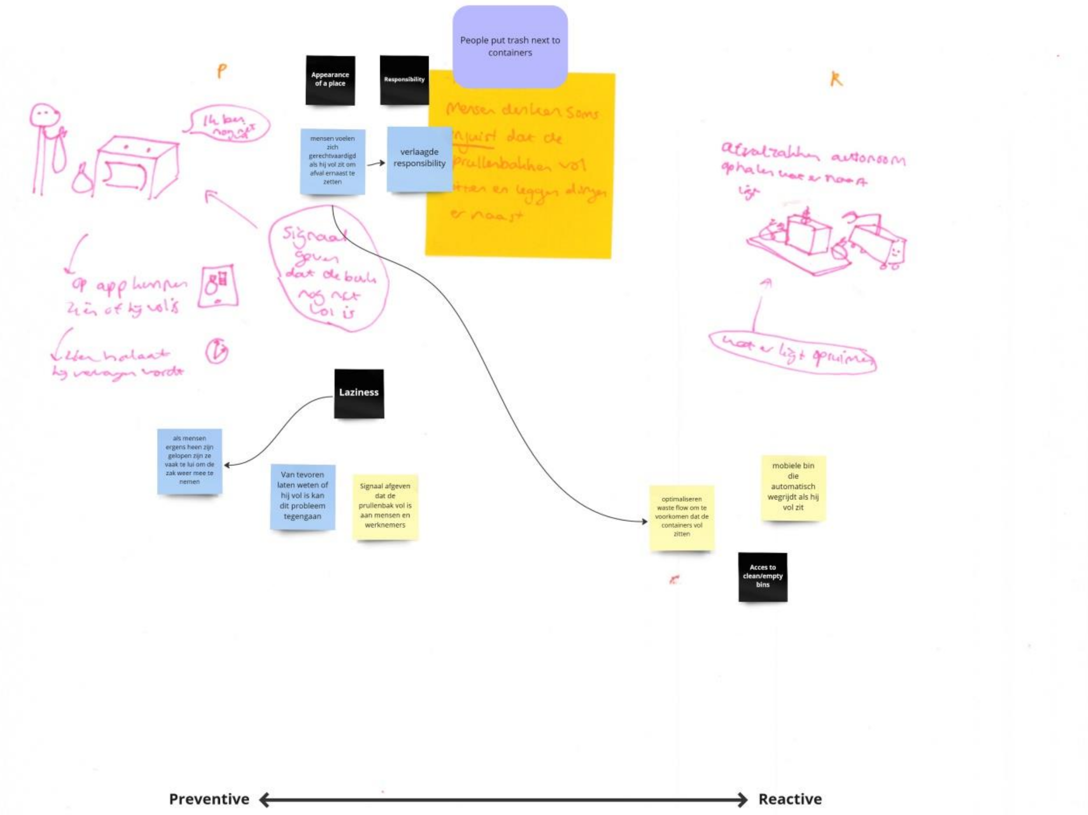
Appendix C Brainstorm Session 2



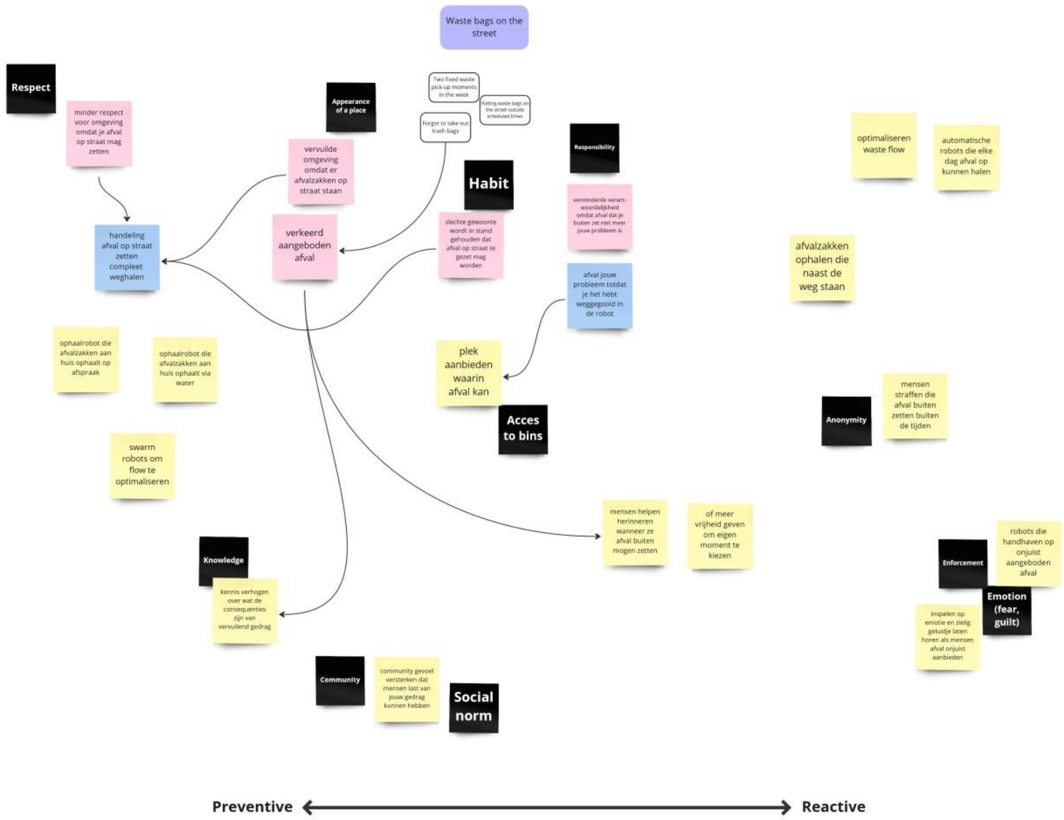


Appendix D Brainstorm Session 3



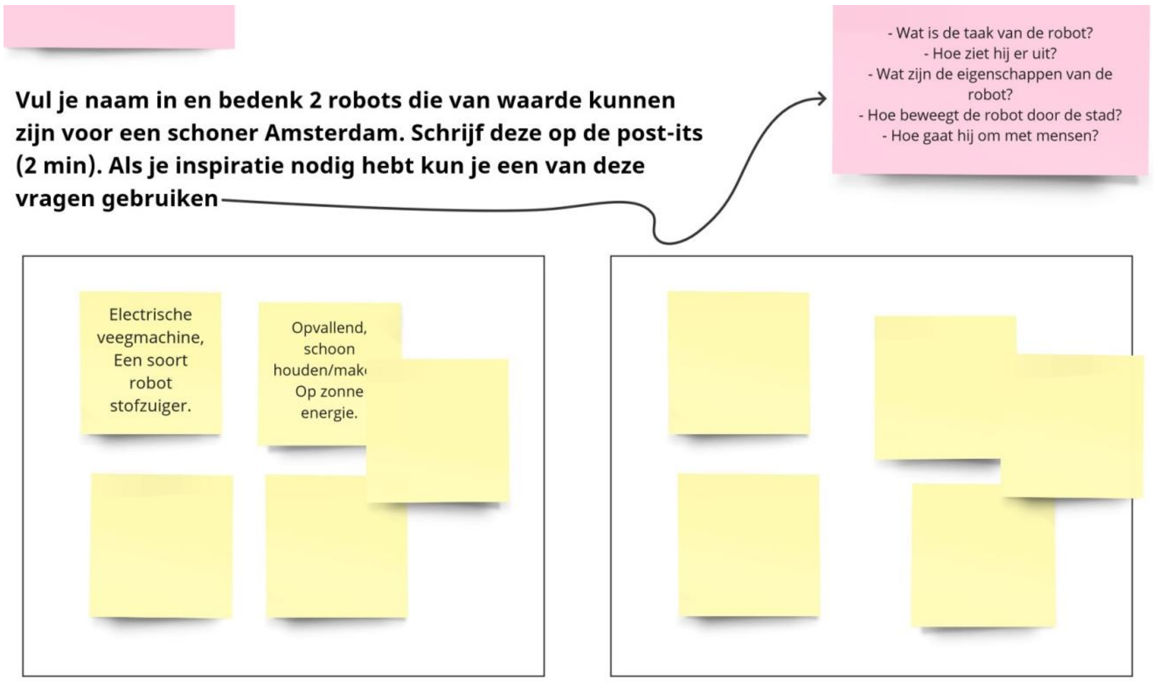


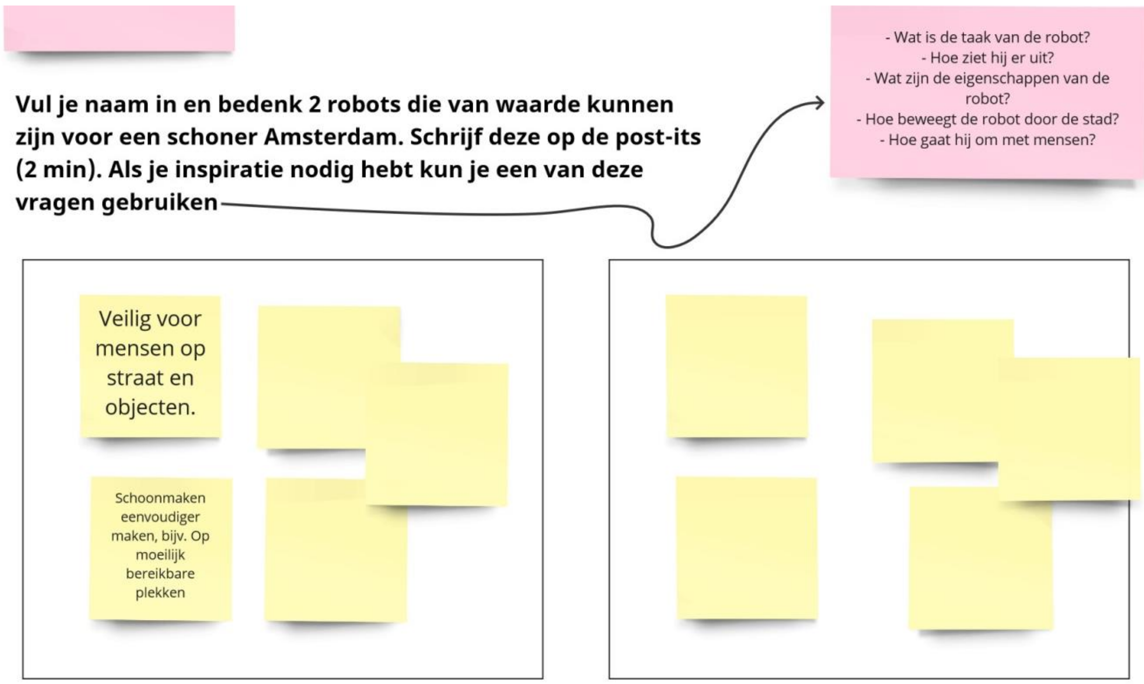
People put trash next to containers
Appearance of a place
Responsibility
mensen voelen zich gerechtvaardigd als hij vol zit om afval ernaast te zetten
verlaagde responsibility
Laziness
als mensen ergens heen zijn gelopen zijn ze vaak te lui om de zak weer mee te nemen
Van tevoren laten weten of hij vol is kan dit probleem tegengaan
Signaal afgeven dat de prullenbak vol is aan mensen en werknemers
optimaliseren waste flow om te voorkomen dat de containers vol zitten
mobiele bin die automatisch wegrijdt als hij vol zit
Acces to clean/empty bins
Preventive
Reactive



Waste bags on the street
Respect
minder respect voor omgeving omdat je afval op straat mag zetten
handeling afval op straat zetten compleet weghalen
Appearance of a place
vervuilde omgeving omdat er afvalzakken op straat staan
verkeerd aangeboden afval
Two fixed waste pick-up moments in the week
Putting waste bags on the street outside scheduled times
Forgot to take out trash bags
Habit
slechte gewoonte wordt in stand gehouden dat afval op straat te gezet mag worden
Responsibility
verminderde verant-woordelijkheid omdat afval dat je buiten zet niet meer jouw probleem is
afval jouw probleem totdat je het hebt weggegooid in de robot
plek aanbieden waarin afval kan
Acces to bins
optimaliseren waste flow
automatische robots die elke dag afval op kunnen halen
afvalzakken ophalen die naast de weg staan
ophaalrobot die afvalzakken aan huis ophaalt op afspraak
ophaalrobot die afvalzakken aan huis ophaalt via water
swarm robots om flow te optimaliseren
Anonymity
mensen straffen die afval buiten zetten buiten de tijden
mensen helpen herinneren wanneer ze afval buiten mogen zetten
of meer vrijheid geven om eigen moment te kiezen
Knowledge
kennis verhogen over wat de consequenties zijn van vervuilend gedrag
Community
community gevoel versterken dat mensen last van jouw gedrag kunnen hebben
Social norm
Enforcement
robots die handhaven op onjuist aangeboden afval
Emotion (fear, guilt)
inspelen op emotie en zielig geluidje laten horen als mensen afval onjuist aanbieden
Preventive
Reactive

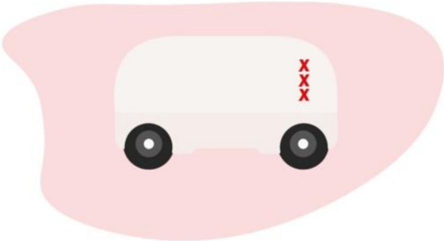
Appendix E Evaluation with the Municipality of Amsterdam and Department Schoon Assignments





Beantwoord de volgende vragen (1 t/m 4) op de post-its. (4 min)

Mobiele Container Robot



1) Hoe goed zou de robot werken in Amsterdam?

- Denk dat de mobiele container het goed zou doen. Omdat het zowel schoon als A&G hier voordeel aan heeft.

2) Wat zijn de sterke punten van de robot?

- Het (grotendeeks) oplossen van illegale bij plaatsingen
- Het is zero emissie.
- Het zal het werk makkelijker en eenvoudiger maken voor de medewerkers.

3) Tegen welke uitdagingen zal de robot aanlopen?

- Dat ondernemers illegaal afval dumpen.
- vandalisme
- Opladen van de containers.

4) Andere opmerkingen/ideeën/feedback etc.

- Iedere robot een eigen naam geven, dit maakt het voor de bewoners/buurt nog persoonlijker.
- De binding met de buurt/bewoner zal toenemen,

Beantwoord de volgende vragen (5 t/m 8) op de post-its. (4 min)

Mobiele Afvalbak Robot

5) Hoe goed zou de robot werken in Amsterdam?

- Denk in de winkelstraten en pleinen beter dan in een woonwijk.

6) Wat zijn de sterke punten van de robot?

- Er is vraag naar oplossingen als deze.
- Milieu vriendelijk.

7) Tegen welke uitdagingen zal de robot aanlopen?

- Op locaties met veel voetgangers zal de robot misschien voor onveilige situaties zorgen.

8) Andere opmerkingen/ideeën/feedback etc.

Beantwoord de volgende vragen (1 t/m 4) op de post-its. (4 min)

Mobiele Container Robot

1) Hoe goed zou de robot werken in Amsterdam?

Ik denk dat dit goed kan werken,. Leuk om voor te leggen aan afval en grondstoffen.

2) Wat zijn de sterke punten van de robot?

Bewoners wordt optimaal gefaciliteerd en kan afval kwijt wanneer hij dat wil.

3) Tegen welke uitdagingen zal de robot aanlopen?

Kans dat hij snel vol zal zijn op bepaalde momenten. Mensen willen niet wachten tot hij weer geleegd is.

4) Andere opmerkingen/ideeën/feedback etc.

Nog innovatiever dan de bakfietsen waarmee nu geëxperimenteerd wordt. Want robot blijft in de buurt.

Beantwoord de volgende vragen (5 t/m 8) op de post-its. (4 min)

Mobiele Afvalbak Robot

5) Hoe goed zou de robot werken in Amsterdam?

Ik vind het wel een proef waard. Ik kan me wel voorstellen dat er ook misbruik van wordt gemaakt, in d

6) Wat zijn de sterke punten van de robot?

Ze zijn op de plekken waar het nodig is, flexibele locatie.

7) Tegen welke uitdagingen zal de robot aanlopen?

Misbruik. Hoe weten ze waar ze naar toe moeten? Reageren ze op een tekst? Kun je ook mee 4acen dan. 😳

8) Andere opmerkingen/ideeën/feedback etc.

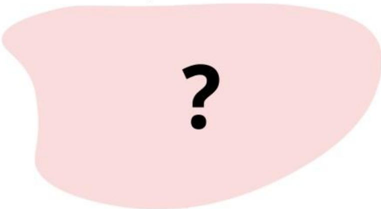
Welke van deze robots vind je de beste oplossing voor een schoner Amsterdam en waarom? Schrijf het op de post-its. (2 min)

Mobiele Afvalbak Robot

Reuzenroomba

Mobiele Container Robot

Jouw idee?

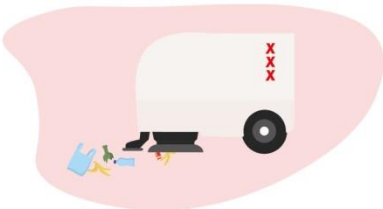


Mobiele containerrobot .huishoudelijk afval zakken zorgen voor veel zwerfafval in binnenstad. Daarna mobiele afvalbakken op bepaalde locaties.

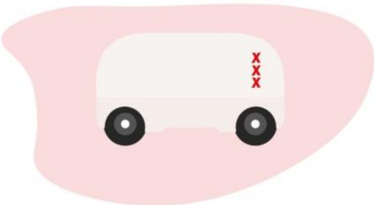
Welke van deze robots vind je de beste oplossing voor een schoner Amsterdam en waarom? Schrijf het op de post-its. (2 min)

Mobiele Afvalbak Robot

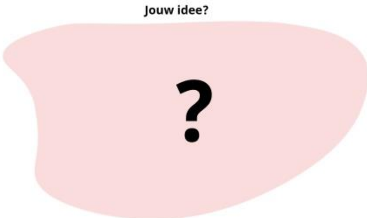
Reuzenroomba



Mobiele Container Robot



Jouw idee?



Mobiele container robot.

Appendix F The Project Brief

Personal Project Brief - IDE Master Graduation

TU Delft

A strategic roadmap for a cleaner city with robots — project title

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

start date 17 - 06 - 2022 — 27 - 01 - 2022 end date

INTRODUCTION **

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

Amsterdam is a big and dynamic city with a lot of residents and tourists. Even though 500 cleaners work every day to clean Amsterdam, it is hard to keep the city clean and reach the cleaning objectives. The management of the public space is carried out with one urban standardization, monitoring and inspection system (1Amsterdam Heel & Schoon, 2016) and the cleaning objectives are determined by the CROW measurement system (CROW, 2018). The objective of the municipality of Amsterdam is 'verzorgd' (well-kept), which corresponds to the objective B of the CROW system (1Amsterdam Heel & Schoon, 2016), see Figure 1. The fact that the cleaning objectives are not reached results in a city that is not as clean as desired, which negatively influences the feeling of safety (Kelling & Wilson, 1982) and pleasantness of the residents and visitors of Amsterdam.

The municipality of Amsterdam wants to provide a clean and safe public environment for their residents to live in. Since the cleaning objectives cannot be reached with the current resources, the municipality wants to explore whether a complementary resource, such as robots, can be of value to tackle this problem.

Another group of stakeholders are the employees of the cleaning department of Amsterdam since they may work alongside the robot in the future. They are expected to work according to the CROW measurement system. My estimation after introductory conversations with the cleaners is that they value a pleasant and social work environment, but their precise needs and values will be an element of this thesis.

I will conduct this project together with the Institute Advanced Metropolitan Solutions (AMS) and the Expressive Intelligence Lab of Delft Design Labs of TU delft. The AMS aspires to create sustainable solutions for the challenges cities face and they want to connect science and societal challenges to solve these together.

Multiple relevant developments are taking place that could have an influence on the context in which the robot will operate in the long term. The city itself is growing, it is expected that Amsterdam will have more than 1 million inhabitants in 2030 (Statista Research Department, 2022), making the city an even busier place. The recovery of tourism (UNWTO, 2022) will also contribute to a more hectic environment. Next to that, trends show that urban mobility will change in the near future, e.g. autonomous vehicles which "could also lead to higher overall vehicle mileage" (Mckinsey, 2017), making the streets more occupied. Another trend, which can be seen as an opportunity for the robot, is that more data is generated in cities. "With the help of artificial intelligence, this data will make our living environment increasingly predictable and manageable" (FreedomLab, 2021). Another opportunity is that "the acceptance of service robots has flourished." (Gonzalez-Aguirre et al., 2021) There are, however, also concerns about service robots (e.g. taking away jobs) that could be an obstacle for the acceptance (PAiCE, 2019).

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introduction (continued): space for images

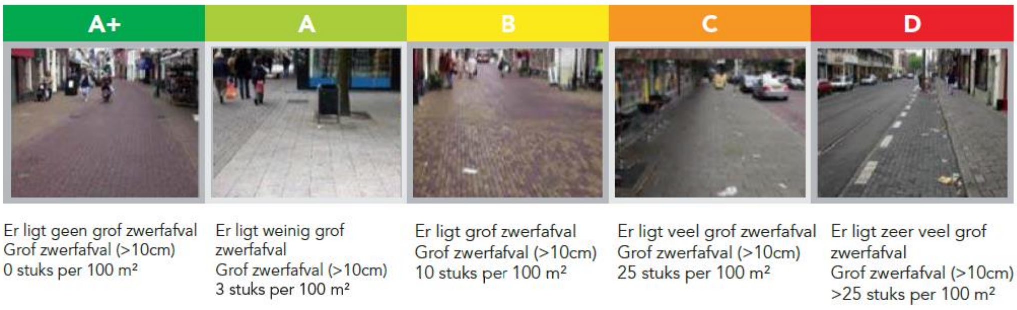


image / figure 1: CROW measurement system

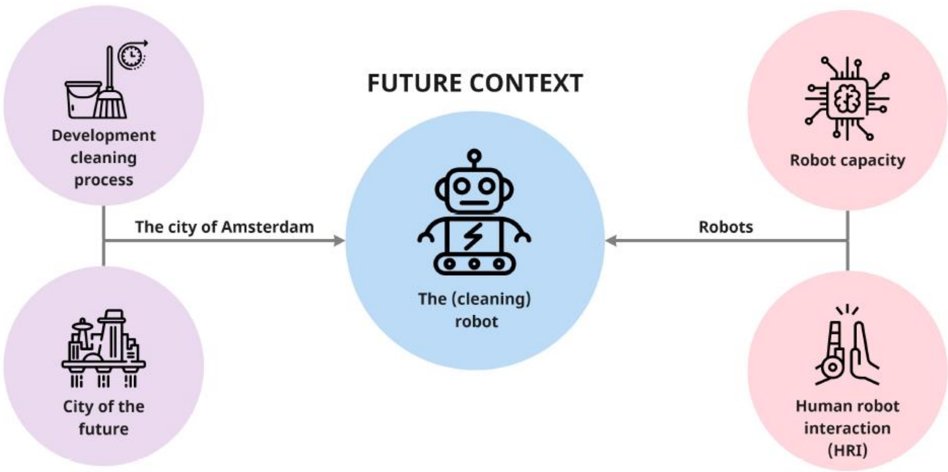


image / figure 2: These four components influence how the (cleaning) robot could function in the long term

PROBLEM DEFINITION **

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

As stated in the introduction, it is currently hard to keep the city of Amsterdam clean even though they have 500 cleaners who clean the streets on a daily basis. This is already negatively affecting the quality of life of the residents and the city's appeal to visitors. The fact that the city will become even more crowded, will exacerbate this waste problem and add to this negative influence. This thesis will be the first step in the exploration of the added value of robots for mitigating this issue.

Next to that, it is not yet clear how the robot can be of value in the cleaning process in the long term. The context in which the robot will function will likely change in the near future, according to the previously mentioned trends. Another influence on the context is the developments in the cleaning process of the cleaning department of Amsterdam. For example, in the near future, iPads will be implemented in the cleaners' working environment, which will probably change the dynamics of the cleaning process. In addition, it is not yet clear how the capacity of service/cleaning robots will develop over time.

These changes of the context need to be taken into account in order for the robot to function properly in the long term and to design a sustainable and pleasant relationship between the robot and humans. I have identified four components that have influence on the robot and divided these into two themes; the city and robots, see Figure 2.
The first theme has two important components that need to be addressed:
- The changing environment of the city
- The developments of the cleaning process of the cleaning department of Amsterdam

The second theme, robots, has the following issues that need to be addressed:
- Human robot interaction (HRI) and the acceptance of service robots
- The future capacity of service/cleaning robots

ASSIGNMENT **

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

I am going to investigate how robots can optimally support the cleaning process in the complex environment of Amsterdam in the long term. Based on gained insights I will create a roadmap with a future vision of how robots can contribute to a cleaner city exemplified with a case study of my roadmap.

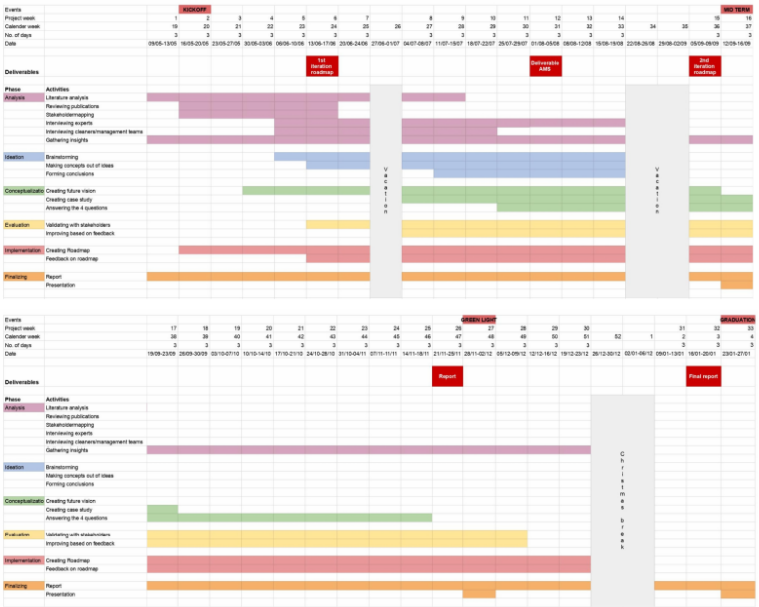
The expected outcome of this project is a strategic roadmap with a future vision of two themes, the city (of Amsterdam) and robots, with four different topics; the city of the future, the cleaning process, Human Robot Interaction and technological developments of robot capacity. This will illustrate how the future vision can be achieved in the long term. In order to visualize how the four different components will influence the context of the robot, these have been translated into the following questions that I will try to answer with this project:
- City of the future → Which tech (e.g. robotics) and demographic (e.g. tourism, population, urban environment) trends in Amsterdam are currently being researched and how will they change the outdoor urban environment in 10 years?
- The cleaning process → What are the underlying factors (e.g. cleaning requirements, budget) that will influence the cleaning process of the cleaning department of Amsterdam in the coming years, and how are those factors changing now?
- HRI → What is the state of the art of HRI collaboration in public spaces with service robots (e.g. cleaning, delivery etc.) and the technology readiness levels?
- Technological developments of robot capacity → What is the state of art in the field of technological developments of robot capacity (e.g. sensing, acting and reasoning) and the technology readiness levels of service robots in public space?

In the process of my project I will specify the questions in more detail.

PLANNING AND APPROACH **

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

start date 17 - 6 - 2022 | 27 - 1 - 2022 end date



In order for the Gantt Chart to be readable in this visual, I have split it in two.

In this project I will work 3 days per week. This was decided in consultation with the study advisor and my chair and mentor.

I will review scientific literature as well as publications of the municipality of Amsterdam and AMS. Next to that, I will conduct qualitative research by interviewing the cleaners and management teams of the cleaning department of Amsterdam and several experts of different areas. With this I will formulate an answer to the previously mentioned questions. Based on the gained insights, I will create a roadmap with a future vision, with multiple possible paths of the future, about how a robot can contribute to a cleaner Amsterdam in the long term.

Sometimes I will work together with another student, Enzo Steehouwer, since he is working on the same subject with a different focus; My focus is on the robot in a future context with a strategic roadmap as deliverable and Enzo focuses on what the robot should do in the context of the present-day taking into account the wishes and needs of the users.

MOTIVATION AND PERSONAL AMBITIONS

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

The reason why I am doing this project is because of the combination of human behavior and robots. This seemed really interesting to me since I am fascinated by why people act in a certain way and technological developments and the impact of these rapid technological changes. Next to that, I like to do qualitative research; talking to people and figuring out what their needs and values are.

I want to broaden my expertise as a designer by creating a strategic roadmap with a vision of the future. I think that a roadmap is a strong tool for communicating with stakeholders and making it clear for everyone what needs to be done in order to get to a certain point in the long-term. Therefore, I want to gain more experience in creating a roadmap and learn about this method.

Another reason why this project is interesting for me is the amount of different stakeholders and the management of these stakeholders. With this project I want to challenge myself to emerge myself in a completely different environment than I am used to. I have never worked before with a municipality and never talked before to (street) cleaners. I believe that a designer should be able to work with different people, so this will be a good opportunity to gain more experience in talking to many different people and involving the stakeholders in this project.

FINAL COMMENTS

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