COLLEAGUES, NOT COMPETITORS

Thomas Raub

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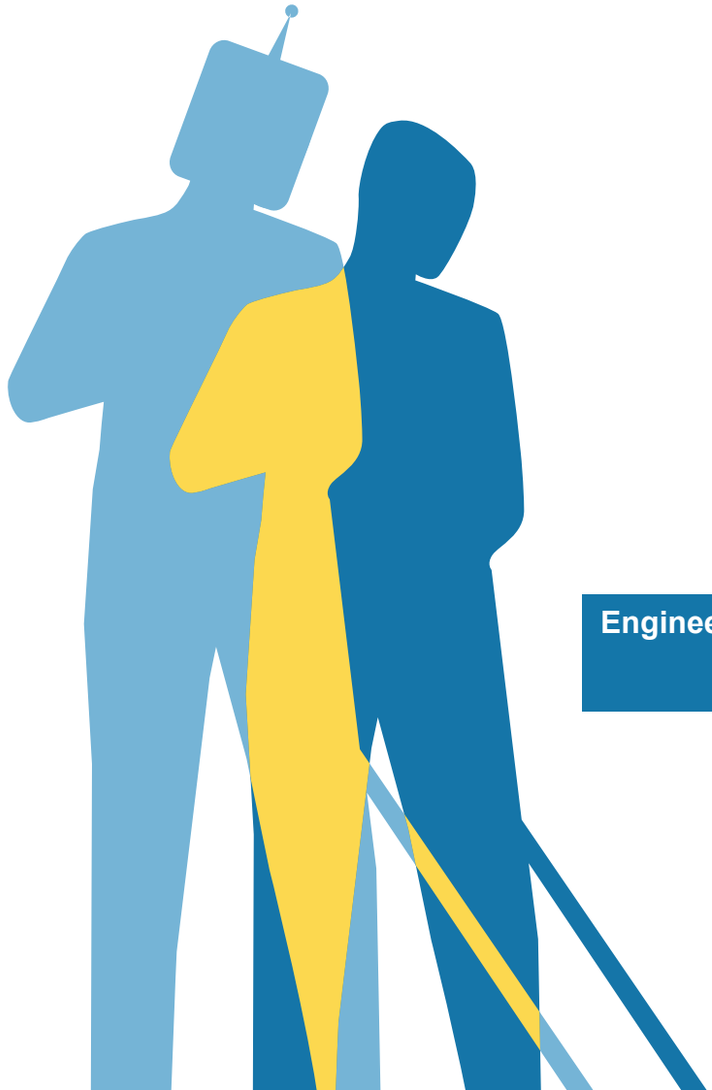
## Development of a Value-based Design Toolbox for Responsible Cleaning Robotisation



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Colleagues, Not Competitors:
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# Foreword

This thesis represents the results of two years of engulfing myself in the Dutch professional cleaning industry. It has been an enlightening and insightful journey, that has hopefully shed light on an industry and a topic that deserve our attention. After all, all of us, whether we are cleaners or academics, surely deserve good work, filled with colleagues we can rely on to have our best interests at heart. Sometimes, those colleagues can be mechanical, but if we do it right, maybe that is okay.

Along this journey, I had the pleasure and honour of enjoying the aid and company of many important people, and it is to those companions that I owe my thanks.

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*And finally, to Walter, because you are who you are, and I do not need any other reason.*

# Samenvatting

De professionele schoonmaakbranche is een belangrijke schakel voor onze maatschappij. De branche zorgt dat onze kantoren en (openbare) ruimten schoon, gezond, en toegankelijk blijven. Er zijn echter verschillende uitdagingen voor de branche, waaronder vergrijzing, een hoge werkdruk, en een lage erkenning en waardering vanuit de samenleving. Deze uitdagingen hebben hun invloed op het welzijn van schoonmakers. Robotisering wordt beschouwd als een mogelijke oplossing om deze problemen te benaderen. Maar vernieuwingen brengen hun eigen uitdagingen en vragen met zich mee. Schoonmaakrobots moeten worden ontwikkeld op een verantwoorde manier, om de uitdagingen van schoonmaakwerk aan te kunnen. Het ontwerp van toekomstige robots moet rekening houden met de gevolgen voor schoonmakers wanneer zij samenwerken met robots om hun schoonmaaktaken te doen. Dit onderzoek bestudeert de impact van robotisering op professioneel schoonmaken. Verder zijn methodes ontwikkeld die het mogelijk maken om verantwoorde schoonmaakrobots te ontwerpen, met betrokkenheid van schoonmakers uit de branche.

Hoofdstuk 2 behandelt schoonmaken en robotisering vanuit de theorie. Deze geven aan dat de zwaarte van het schoonmaken een van de belangrijkste uitdagingen voor de branche is. Schoonmakers hebben bovendien last van vooroordelen en een gebrek aan zichtbaarheid en erkenning voor hun werk. De huidige markt van schoonmaakrobots richt zich hoofdzakelijk op de functionele optimalisering van schoonmaaktaken, en minder op de sociale dynamiek van een passende samenwerking tussen mens en robot. Er is daarbij minder aandacht voor de aspecten die mensen belangrijk vinden om hun werk aangenaam en betekenisvol te maken, dat wil zeggen hun persoonlijke waarden. Eerdere onderzoeken naar mens-robot samenwerking geven het belang aan dat robots de verwachtingen kunnen vervullen van hun menselijke gebruikers. Bovendien is er de mogelijkheid dat wanneer robots steeds meer sociale functies krijgen, zoals kunnen spreken en kunnen luisteren naar de stem van de schoonmaker, zij een sterke collegiale band kunnen vormen met mensen. Robotisering zal naar verwachting een impact hebben op de werktevredenheid van schoonmakers, en een passende werkverdeling is daarbij belangrijk. Het werk moet betekenisvol blijven, door robots te ontwikkelen die schoonmakers ondersteunen, en goede en betrouwbare collega's kunnen zijn.

In hoofdstuk 3 wordt een workshop beschreven met experts vanuit de schoonmaakbranche. Deze workshop verkent het huidige schoonmaken, en de visie van de experts op verbetering van schoonmaken in de toekomst. De resultaten hiervan zijn geanalyseerd om te bepalen welke persoonlijke waarden op het spel staan bij robotisering, en hoe deze zich verhouden tot bredere eisen voor welzijn. Deze eisen voor persoonlijk welzijn zijn gebaseerd op de zelfbeschikkingstheorie, en bestaan uit autonomie, competentie, en verbondenheid. De resultaten van de workshop geven aan dat de eerdere genoemde thema's van gezondheid, stigmatisering, en zichtbaarheid een belangrijke rol spelen in de praktische ervaringen van deelnemers.

Hoofdstuk 4 onderzoekt de robotisering van schoonmaken vanuit een organisatorisch perspectief. De relaties en interacties tussen klanten, werkgevers, werknemers, en robots zijn gemodelleerd om vanuit de betrokken organisaties te bepalen wat de uitdagingen en obstakels zijn voor robotisering. Op technologisch gebied zullen robots gebruik maken van sensoren en data om hun taken te kunnen volbrengen, en ze zullen daarom toegang tot die gegevens nodig hebben. Dit stelt eisen aan de ICT systemen. Sociaal gezien is het voor robotisering belangrijk dat er acceptatie is voor de technologie, vanuit werkgevers, klanten, en schoonmakers. Dit benadrukt het belang voor een verantwoorde ontwerpbenadering

voor schoonmaakrobots, waarin belanghebbenden kunnen meebeslissen. Zo kan de technologie aansluiten bij de waarden en wensen van de gebruikers.

In hoofdstuk 5 wordt de design toolbox voor verantwoorde schoonmaak robotisering ontwikkeld. De toolbox bestaat uit methodes en materialen voor het uitvoeren van workshops met schoonmakers en anderen, waarin gezamenlijk robots voor de professionele schoonmaak worden ontwikkeld. De methodes zijn ontworpen om ten eerste deelnemers te laten nadenken over hun visie voor de toekomst van schoonmaken en robotisering, en daarmee hen aan het denken te zetten over hoe hun waarden op spel staan wanneer de robots worden ingevoerd. Bovendien worden zij ondersteund om actief deel te nemen in het ontwerpproces, en nieuwe ideeën voor verantwoorde schoonmaakrobots te ontwikkelen. De toolbox kan daarmee het schoonmaakrobot ontwerpproces meer toegankelijk maken voor iedereen uit de branche, en een gezamenlijk platform voor discussie geven over de waarden die van belang zijn voor schoonmaak robotisering.

In hoofdstuk 6 wordt de toolbox geëvalueerd door middel van workshops met ontwerpers en schoonmakers. De methodes en materialen worden in deze workshops toegepast om te bepalen of zij succesvol deelnemers kunnen betrekken in het waarden-gerichte ontwerpproces van toekomstige schoonmaakrobots. Op basis van de resultaten van deze workshops is aangetoond dat het deelnemers vanuit de branche is gelukt om de meeste onderdelen van de toolbox goed toe te passen. Bovendien gingen de deelnemers discussiëren over schoonmaakwerk, hun eigen visie en wensen, en de waarden die voor hen van belang zijn bij robotisering. De toolbox bleek echter vooralsnog te beperkt te zijn voor de ontwikkeling van een volledig gedetailleerde robot concept met deelnemers. Aanbevelingen zijn gemaakt om de toolbox onderdelen verder te ontwikkelen, waaronder de toevoeging van nieuwe methodes en materialen voor het specifieke doeleinde van gezamenlijke concept ontwikkeling.

De resultaten van dit onderzoek kunnen worden toegepast in de schoonmaakbranche om waarden-gericht ontwerpen van robots met belanghebbenden te ondersteunen. De ontwikkelde methodes kunnen bovendien worden aangepast voor gebruik in andere branches, om te zorgen voor een positieve impact van technische vernieuwingen. De waarden-gerichte aanpak en zelfbeschikkingstheorie bleken effectief om de uitdagingen en ervaringen van schoonmakers en andere belanghebbenden bij schoonmaken te verkennen. De volgende stap zal zijn om de ontwerp methodes te implementeren in de praktijk, en om verder te onderzoeken hoe schoonmaakrobots kunnen bijdragen aan een betere schoonmaakbranche in de toekomst.

# Summary

The professional cleaning industry is an essential facilitator for our modern society. The industry keeps our offices and public spaces clean, healthy, and accessible. It is also an industry that faces great challenges, including an aging workforce, high workload, and a low level of appreciation by the public. These challenges place pressure on the bodies and minds of human cleaning workers. Robotisation has been raised as a potential solution to tackle these issues, but such innovations bring challenges and questions of their own. Cleaning robots will need to be developed in a responsible way, to address the challenges of current professional cleaning work. The design of future robots must address the impact on the sociotechnical values and core wellbeing needs of human cleaners as they collaborate with robots to fulfil their cleaning tasks. The research in this thesis addresses the impact of robotisation on professional cleaning work. To make the insights actionable for designers, a toolbox is developed to facilitate the value-centred and participatory design of future cleaning robots with stakeholders.

Chapter 2 offers a theoretical review of the context of professional cleaning work and its robotisation. Findings indicate that that the physical and mental strain placed on workers is one of the main challenges that must be addressed within the industry. Workers are moreover dealing with stigmatisation as dirty workers, and an ensuing lack of visibility and recognition. The current market of cleaning robot products was found to focus on a function-oriented approach of task optimisation, rather than fully exploring the social dynamics of a suitable human-robot collaboration. There is moreover an apparent lack of consideration for value-based concerns in cleaning robot design. In line with studies on human-robot work collaboration, a key proposition of this thesis is that robots will need to be able to meet the expectations set by their human operators. Previous research furthermore indicates that as labour robots become endowed with more social features, there is potential for close, collegial bonds to be formed between human and robot workers. The process of robotisation can be expected to affect the overall job satisfaction of workers, and a suitable task allocation will need to be developed. The meaningfulness of workers' contributions must be preserved, by designing robots that suitably support workers in their tasks.

In chapter 3, the findings from theory are supplemented with empirical data gathered through a workshop with cleaning industry professionals. This workshop explored the stakeholders' experiences with current cleaning work, as well as their vision for improvement of cleaning work in future. The participants' contributions were analysed to determine sociotechnical values at stake in robotisation, and related to an overarching framework of core wellbeing needs based on self-determination theory, consisting of autonomy, competence, and relatedness. Results of the workshop showed that the aforementioned issues of health, stigmatisation, and visibility play an important role in the practical experience of workers within the industry. It was furthermore found that issues of for example independence, social interaction, and professional growth represent important values for the participating stakeholders. The experiences and visions shared by participants moreover gave specific meaning to those values and topics, providing insights in why they are important and how they should be addressed. SDT was found to offer a suitable core of wellbeing needs that robots must support.

Chapter 4 explores the shift towards robotisation of cleaning tasks from an organisational perspective. The relationships and interactions between clients, employers, and workers have been modelled based on the framework of enterprise architecture. These models revealed challenges and obstacles for the organisational transition towards robotisation

of the incumbent system. Technologically, the robots will be relying on sensors and data to fulfil their tasks, for which there must hence be an accessible data infrastructure. Socially, the robotisation more importantly relies on acceptance of the technology by stakeholders, including employers, clients, and cleaning workers. This re-establishes the need for a responsible, value-based, and participatory design approach to cleaning robots, that ensures the technology aligns with the values and needs of stakeholders, particularly the cleaning workers as end-users.

Chapter 5 addresses the design toolbox for responsible cleaning robotisation, based on the preceding research on theory, empirical practices, and organisational transitions. The toolbox consists of methods and materials for conducting participatory workshops with stakeholders in professional cleaning work. These contents were designed with the purpose of enabling stakeholders to first reflect on their vision for future cleaning work and robotisation, and exploring how their values are at stake as the technologies are implemented. Furthermore, the toolbox supports stakeholders to actively participate in the design process to generate new concepts for responsible cleaning robots that support cleaning workers. The toolbox can make the cleaning robot design process more accessible for stakeholders of different backgrounds within the cleaning industry, as well as create a common understanding and platform for discussion about the values that are important within cleaning robotisation.

In chapter 6, the toolbox was evaluated through workshops with designers and professional cleaning workers. The workshops applied the methods and materials of the toolbox to determine their overall usability and their effectiveness for engaging participants in a value-centred and participatory design process for future cleaning robots. Based on the results of these workshop, the toolbox contents were largely found to be usable and understandable for industry participants. Moreover, the tools successfully facilitated participants' discussions about cleaning work and their future vision and needs, and revealed and specified the values they deem important and at stake in cleaning robotisation. However, the toolbox was found to be too limited for the purpose of fully detailed concept generation. Suggestions have been made for further improvement of the toolbox components, including the addition of new methods and materials for the specific purpose of collaborative concept generation.

The results of this research can be applied within the professional cleaning industry to support the value-centred and participatory design of future cleaning robots. The tools developed can moreover be adapted for application in other occupations, to ensure a positive impact for future innovations. The value-based approach as well as self-determination theory that were applied in this research were found to be effective means for exploring the inherent challenges and experiences of workers and other stakeholders within professional cleaning. The recommended next step will be to implement the design toolbox into cleaning robot design practice, and to further explore how cleaning robots can contribute to a better professional cleaning industry for the future.

# Contents


1. Introduction ..... p.13

2. Background review of professional cleaning industry and robotisation ..... p.16

2.1. Characteristics and challenges of cleaning industry ..... p.16

2.2. Current cleaning robotics products ..... p.19

2.3. Human-robot interaction and collaboration ..... p.23

2.4. Discussion ..... p.31

2.5. Conclusions ..... p.32

3. Exploring cleaning industry values through a stakeholder workshop ..... p.34

3.1. Background and theoretical frameworks ..... p.35

3.2. Workshop methodology ..... p.40

3.3. Participants' results ..... p.43

3.4. Analysis of workshop results ..... p.47

3.5. Discussion ..... p.51

3.6. Conclusions ..... p.52

4. Modelling of organisational transition for cleaning robotisation ..... p.54

4.1. Organisational context ..... p.55

4.2. Architecture requirements analysis ..... p.56

4.3. System design ..... p.59

4.4. Discussion ..... p.63

4.5. Conclusions ..... p.64

5. Design toolbox for responsible cleaning robotisation ..... p.66

5.1. Value-based design principles ..... p.66

5.2. Toolbox components ..... p.68

5.3. Discussion ..... p.76

5.4. Conclusions ..... p.77

6. Evaluation of design toolbox for responsible cleaning robotisation ..... p.78

6.1. Workshop 1: Designers ..... p.78

6.2. Workshop 2: Cleaning workers ..... p.84

6.3. Discussion ..... p.92

6.4. Conclusions ..... p.94

7. Discussion ..... p.96
7.1. Values for responsible cleaning robotisation ..... p.96
7.2. Applicability for other domains ..... p.100
7.3. Value-based design ..... p.102
7.4. Self-determination theory ..... p.104
7.5. Future vision ..... p.105
7.6. Closing remarks ..... p.106
References ..... p.107
Appendix ..... p.115

# 1. Introduction

> *"Technologically it is possible to develop an autonomous cleaning robot, […] but questions remain as to the financial viability of products and the motivation of the industry to develop new working practices necessary for their use. We need to extend our systems thinking to include consideration of autonomous robots in the broader human context if service robots are really to achieve economic and social acceptance."* (Schofield, 1999, p. 1434)

The professional cleaning industry is an essential facilitator for our modern society. The industry keeps our offices and public spaces clean, healthy, and accessible. It however also currently faces great challenges, including an aging workforce, high workload, and a low level of appreciation by the public. These challenges place pressure on the bodies and minds of human cleaning workers. Robotisation has been raised as a potential solution to tackle these issues, but such innovations bring challenges and questions of their own. How will the daily work life of cleaners change when they work together with robots? What will be the impact on organisations when they implement robots for cleaning? And what are the values that are at stake when cleaning robots are brought into this system?

Addressing these questions will require the companies investing in cleaning robots and the organisations developing the robots to take an approach to their design that is sensitive to these concerns and the needs and wishes of stakeholders. These include the employers at cleaning companies, their clients, and particularly the cleaning workers who will be the technology's end users. These users must have a voice represented in the robot development and implementation process. This will require the use of design tools and materials that facilitate this participatory value-based approach, and which are aligned for the specific context of professional cleaning work.

The goal of the research project presented in this thesis will hence firstly be the study of the impact of robotisation on professional cleaning work, the core needs for wellbeing therein, and the sociotechnical values at stake. Secondly, the research includes the development of a toolbox of participatory design tools for the responsible design of future cleaning robots, which enable stakeholders to reflect on and discuss the impact of cleaning robots on the values at stake in cleaning work. Designers will be able to use the results of these discussions to develop robots that contribute to a better cleaning work future, by including the values and concerns of stakeholders.

This project was conducted in collaboration with and through funding from the Dutch Council for Working Conditions in the Cleaning Industry (Raad voor de Arbeidsverhoudingen in de Schoonmaak- en Glazenwassersbranche, RAS). The RAS approached the DesignLab of the University of Twente to research the impact of robotisation on cleaning work. During the project they furthermore acted as an intermediary for contacting and collaborating with industry stakeholders. The scope of the research is focused on the cleaning industry within the Netherlands. The focus is moreover on improving the robot design process itself, and studying the sociotechnical values that are at stake in robotisation, rather than on the design of specific new cleaning robot concepts. The research was completed as part of a collaboration with a partner EngD project, also on behalf of the RAS. This partner project is focussed on the conceptualisation and prototyping of a full cleaning robot product, and hence will make use of the results generated through the research presented in this thesis to ensure a responsible and value-centred robot design process and resulting product.

The topic of cleaning robotisation is studied through a value-based research approach, that focuses on defining the sociotechnical values that are at stake for industry stakeholders, and the impact that robotisation will have on those values. In addition, the framework of self-determination theory is used to explore core needs for personal wellbeing in work. To this end, the following chapters will first develop through literature research, stakeholder study, and organisational modelling the core challenges, themes, and values of interest in cleaning robotisation. These are then incorporated into participatory design tools that enable designers and stakeholders to explore the values more deeply, as well as determine additional values of interest. This will result in the design and validation of a value-based design toolbox for responsible cleaning robotisation.

Chapter 2 will discuss the background of the research from different perspectives. The current state and challenges of the Dutch cleaning industry will be described. Based on a market review of current cleaning robot products, the current market is studied. To explore the potential impact of robotisation on humans and specifically workers, a selection of previous studies in the field will be reviewed and discussed. This chapter will thereby through a theoretical lens introduce the core challenges that robotisation of cleaning work must tackle, as well as provide an initial selection of values and themes that will need to be accounted for in the value-based robot design process.

Chapter 3 will discuss an empirical workshop study that was conducted with stakeholders from the Dutch cleaning industry. This workshop was conducted to address an apparent lack of consideration for value-based concerns in cleaning robotisation. This chapter was originally written as a research paper, which was presented at the Philosophy of Human-Technology Relations conference 2022. The workshop's procedure and results will be described. The purpose of the study was to determine the vision of stakeholders for the future of cleaning work, as well as the values that they consider important and at stake within the robotisation process. The results of the study will be related to the framework of self-determination theory, which distinguishes the three core human wellbeing needs of autonomy, competence, and relatedness. The study thus explores the viability of this framework within the specific context of cleaning industry robotisation. This chapter will thereby provide a practical perspective on cleaning work, through the perspectives of industry stakeholders, and define values and themes that will be relevant for value-based cleaning robot design. These values and themes will be incorporated into the design toolbox for responsible cleaning robotisation.

Chapter 4 will discuss the robotisation of cleaning industry from an enterprise architecture perspective. The organisational relationships and interactions between clients, employers, and workers have been modelled on the three layers of business, application, and technology. A baseline of the industry's current state is modelled, as well as a target architecture that incorporates robotisation. This chapter will thereby explore the organisational systems of the professional cleaning industry and its robotisation to determine challenges that must be met in the robotisation process, as well potential approaches for overcoming them. Addressing these organisational challenges will require addressing the values of stakeholders, and involving them in the robotisation process, to ensure that a sufficient level of interest and acceptance for the technology is achieved. The design toolbox for responsible cleaning robotisation will be designed to support this.

Chapter 5 will discuss the development of workshop materials and activities for a cleaning robot design toolbox. The purpose of the toolbox is to support the use of participatory design approaches, that enable robot designers to include the concerns of stakeholders within the cleaning industry, and that enable those stakeholders to explore the impact of

robotisation on their values and work practice. The toolbox's contents consist of materials made specifically for the context of cleaning robotisation, including use scenarios, provotype cleaning robot concepts, and scenario generation cards. The toolbox incorporates the results of previous chapters on the values and themes to account for.

Chapter 6 will discuss two workshop studies that were conducted to test the proposed design toolbox materials, and thereby evaluate and validate them. The first workshop was conducted as a pilot, with design students, to assess the overall usability of the toolbox contents and feasibility of the workshop set-up. The main workshop was conducted with cleaning workers, to assess whether the toolbox meets its goals for supporting value-based design and enabling participants to explore their values. This chapter will thereby evaluate the design toolbox, and enable recommendations for improvements to be made in the materials and their use in workshops.

# 2. Background review of professional cleaning industry and robotisation

To study the topic of responsible robotisation in the professional cleaning industry, we must understand the context in which this robotisation will take place to address existing challenges, as well as the current market of cleaning innovations and cleaning robot products, and the state of research on human-robot collaboration. The following chapter will explore the overall context of robotisation in cleaning, focusing on three aspects of the topic. First, the core characteristics and challenges of the Dutch professional cleaning industry and cleaning work, particularly as they exist currently, will be discussed. This will allow us to determine the trends in the industry, what challenges must be addressed through innovation and robotisation, and what factors will need to be taken into account when considering robotisation. Second, a discussion will be provided of cleaning robot products that have been made available thus far, or are currently in development. Based on this, we will discuss the current state of cleaning robots, and apparent trends within the current market of cleaning robot products. Third, there will be a review of relevant literature and theory on the topics of human-robot relations and the impact of robots on work. This will enable a theoretical exploration of the potential effects of work robotisation, and factors that must be accounted for in the responsible design and implementation of new work robots. On the whole, this chapter will thus introduce the challenges that robotisation of cleaning work must tackle, as well as providing an initial selection of values and themes that will need to be accounted for in the robot design process.

## 2.1. Characteristics and challenges of cleaning industry

Professional cleaning work comprises a large industry globally, employing a wide range of people. The industry is a key economic driver, and plays an important role in facilitating health and efficiency in the daily life of workers and citizens (Horrevorts, 2016; Horrevorts, Van Ophem, & Terpstra, 2018). The industry however also faces certain challenges. Cleaning work can have long-lasting effects on the health of cleaning workers, both mental and physical, due to the stress that is placed on their minds and bodies. There are also certain social challenges, such as the public stigmatisation of the ‘dirtiness’ of cleaning work. In addition to financial considerations, these factors drive an interest for innovation within the industry, including robotisation but also other technologies. In the following, there will therefore be an exploration of the general characteristics of the cleaning industry, specifically focused on the state of the industry in the Netherlands, the current challenges and risks of cleaning work, as well as the current innovation paths that can be seen.

### Industry demographics

An industry survey conducted by TwynstraGudde on behalf of FMN (2020) reported the market size of the Dutch facility and workplace service market in 2018 to have been approximately 32,5 billion euros, of which cleaning services specifically made up 4,6 billion. According to the same report, cleaning services employed 170.000 people, working for 15.000 services providers. Demographically, a report by RAS (2014) indicates that approximately 70% of Dutch cleaning industry employees are female, and 45% are immigrant workers. The industry moreover employs a high number of workers with low education, as well as people with low literacy and mastery of the Dutch language. There

are many parttime contracts in the industry, with 60% of workers having contracts of less than 19 hours per week. As a result, the average yearly income in the industry is relatively low, at €12.098,-.

## Health challenges in cleaning work

On the personal health level of cleaning workers, there is a significant impact that labour in cleaning work can have. Cleaning work involves a high amount of physical labour, which places considerable strain on the bodies of workers. Søgaard, Blangsted, Herod, and Finsen (2006) indicate that particularly the cardiovascular and musculoskeletal systems of workers undergo significant stress. For floor cleaning specifically, the muscle load appears comparable to that of highly repetitive, machine-paced work, but is overall more strenuous for the shoulder muscles. This leads to increased risk factors for the development of shoulder and neck disorders in cleaning workers. Furthermore, the high cardiovascular load on cleaners in their study exceeded guidelines set forth by various labour organisations. Industry developments like privatization and centralization, as well as specialization into specific types of cleaning amongst cleaning companies, have also led to pressure for optimised efficiency on the part of cleaning workers, thereby exacerbating problems. New technologies like mopping systems and techniques, and organisational rescheduling such as switching between cleaning and non-cleaning tasks, have been proposed as potential solutions. However, experiments by Søgaard et al. (2006) show that these particular innovations failed to successfully alleviate physical stress.

Cleaning work can similarly place strain on the mental health of workers. In addition to the muscle load placed on bodies, Søgaard et al. (2006) describe how cleaning tasks are often monotonous and repetitive in nature, which can lead to stress and boredom due to a poor psychosocial work environment. They moreover describe there being little space for ambition, personal development, and social contact and support. This can furthermore inhibit workers from finding meaning in their work, and is thereby also detrimental to their work satisfaction (Isaksen, 2000; Rothausen & Henderson, 2019; Spector, 1997). Such lack of work satisfaction can have a very negative impact on the mental wellbeing of workers.

## Social perception of cleaning work

From a social standpoint, the cleaning sector, and the people working in it, have been likened to ‘dirty work.’ Ashforth and Kreiner (1999) define dirty work as tasks and occupations that are likely to be perceived as disgusting and degrading. Moreover, the groups that these tasks are delegated to are then stigmatised, as the workers themselves come to be associated with the dirty work. They become seen as ‘dirty workers.’ Within the categories of occupational taint defined by Ashforth and Kreiner (1999), cleaning work would be categorised as physically tainted, due to its relation to physical dirt and dirty environments. There is also a degree of social taint, due to the subordinate role that is often projected onto cleaning workers. This type of stigmatisation can get reinforced by for example stereotypes in media, and also embodied by co-workers and clients treating workers in accordance to the existing cultural stereotypes. Since people typically ground a significant portion of their identity in their roles and occupations, such labels associated with ‘dirty work’ could prevent workers from feeling pride and satisfaction in their labour. In a study of garbage workers by Hamilton, Redman, and McMurray (2019), it was found that contact with physical dirt can negatively affect the experience of dignity in work, expressed through dismissive behaviour by the public and stereotypes about workers having low intelligence. Since professional cleaning workers are similar to garbage workers in that they engage with physical dirt, they will likely have similar experiences.

Dirty work can moreover become 'invisible,' as was found to be the case for cleaning work by Rabelo and Mahalingam (2019). 'Invisible' work is that which "may or may not be visible but is not recognized … hidden, unrecognized, unaccounted-for or taken-for-granted" (Vlasses, 1997, p. 1). Occupational context can lead to employees that are chronically ignored and thereby invisible. This could be as a result of stigmas leading to customers failing to make eye-contact, organizational practices such as overnight shifts, or sociospatial mechanisms such as certain work being physically separated from the public. Each of these can apply to cleaning work, being a stigmatised sector that often for example uses overnight shifts and plans routes so that rooms are cleaned while no other people are present. Cleaners experience different types of invisibility, namely invisibility *at* work where they themselves are (metaphorically or literally) unseen, and invisibility *of* work where their labour is (metaphorically or literally) unseen. The cleaners involved in the study by Rabelo and Mahalingam (2019) reported feelings of shame, anxiety, sadness, resignation, but also acceptance and relief at being invisible while working. Finally, an association with dirty work can lead to workers becoming dehumanized and objectified (Terskova & Agadullina, 2019). Objectification describes when workers become perceived as equivalent to objects. Terskova and Agadullina (2019) describe this to be particularly a risk for occupations that can be (partially) done by machines, so this hence is an important factor to take into account when considering robotisation. Potentially, the Covid-19 pandemic may have impacted the public perception of cleaning work as stigmatised and invisible. The pandemic has led to some stigmatized industries becoming seen as essential services, and their workers became labelled as heroes (Mejia et al., 2021). However, this improved perception was found to be less significant for occupations tainted by dirty work, such as cleaning, which are often less visible to the public (Ashforth, 2020).

## Innovation trends in the cleaning industry

With regards to innovation within the industry, a report by the French Federation of Cleaning Compagnies (FEP, 2019) describes the current innovation trends in professional cleaning. First, they describe the concept of Connected Mobility, that is to say the telecommunication of data. Management platforms can be used to connect cleaning companies with their external workers, in other words their workers at clients, and communicate with them. This would allow for optimisation of customer relationships. Similarly, other online platforms and software packages could be used to dematerialise back-office processes, such as support services and administration, by providing them digitally and online. Robotisation also factors into their trends, which they envision as an implementation of cobotics, a collaboration between humans and robots.

There are also visions for the use of Internet-of-Things (IoT), making use of sensors to retrieve data about the cleaning environment. This could enable bespoke cleaning services, such as cleaning rooms only when sensors detect they need cleaning. Another potential trend is the use of virtual reality, which could be used for training staff and managers, as well as experimenting with quality control. Trends similar to these are described specifically for the Dutch cleaning market in an industry report by the cleaning company Hago (2020).

That said, while these technological trends are visible within the industry, it has also been observed that technological developments such as those described are often only put into practice through short-term pilot-projects, with few innovations being adopted long-term. This has been attributed to a lack of acceptance within the industry, from both cleaning companies and their employees. An innovation like robotisation will hence need to contend with achieving the required level of acceptance to be successful.

## 2.2. Current cleaning robotics products

Within the current market, there have already been certain products introduced that aim to replace specific cleaning tasks with robots. Other concepts are still in development, with plans to be brought to market in the future. There are notably different approaches and trends to the type of robotics technology that is being designed, as well as the types of tasks that are being taken over from human cleaners. The following section will provide a brief study of the market of current cleaning robot products, as well as visible trends within the industry.

### Market review

The robots discussed in the following review are chosen based on an existing market review conducted by Dutch cleaning industry outlet Service Management (2020). The robots will be briefly described, based on their cleaning specialisation for particular tasks, and overall working principles and features. This information is largely based on public communications and marketing materials from the producers of the robots.

The Cleanfix RA 660 Navi (figure 2.1.) is a scrubber-drier cleaning robot that can clean floors (Cleanfix, 2020b). It can navigate autonomously, and scrub areas with a series of brushes. Sensors can perceive the environment, and detect obstacles. Based on this, it can plot its own route through the space to clean it.

The TASKI Duobot 1850 (figure 2.2.) is similarly a scrubber-drier floor cleaning robot, that can also sweep (TASKI, 2017). Dirt and trash is stored in an internal compartment. The robot's cleaning route is pre-programmed during first use by an experienced operator. Using its sensors, the robot can detect and avoid obstacles in its path. Through light and audio signals, the robot communicates status and presence to humans in its surroundings. It can also provide reporting about its cleaning performance to operators and management to allow for consistent monitoring.

The Fraunhofer Institute's Care-O-bot 3 robotics platform was adapted in a study by Bormann, Hampp, and Hägele (2015) to conceptualise an autonomous cleaning robot that could offer a variety of cleaning services (figure 2.3.). The robot can navigate its assigned environment through sensors to detect obstacles, and plan its own efficient route. They moreover developed sensors and software that could detect dirt, enabling the robot to only clean spaces where this is necessary. The robot has multiple cleaning

fig. 2.1. Cleanfix RA 660 Navi (Cleanfix, 2020a)


fig. 2.2. TASKI Duobot 1850 (TASKI, 2017)

attachments that it can switch between, enabling it to vacuum, pick up trash from the ground, and empty trash bins.

The Annie Trash robot (figure 2.4.) was an experimental pilot-project by Hago Airport Services (2021). The robot was used at the airport Schiphol, and aimed at increasing travellers' awareness of the trash they were leaving behind, and thereby reduce littering at the airport. The robot functions as a trash bin that can move through the environment autonomously, detecting obstacles and humans around her. She can approach visitors, and using a friendly design and audible voice reminds them about proper trash disposal, inviting them to throw any trash they have into her compartments.

Emma (figure 2.5.) is a robot developed by the company International Cleaning Equipment (ICE, 2022b). She is a scrubber-drier robot that is capable of fully autonomous navigation, that can avoid obstacles in the environment. The system generates reporting about the use of the robot, providing data for managers to monitor operation. She can moreover be alternatively driven manually by the human operator, like a regular scrubber-drier machine, by turning off the automated robot setting.


fig. 2.3. Care-O-bot 3 autonomous cleaning robot (Bormann et al., 2015)

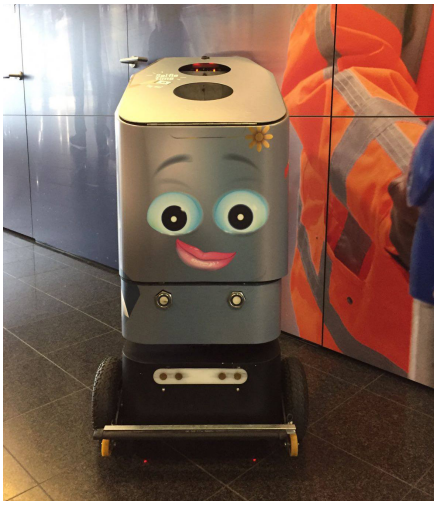

fig. 2.4. Annie Trash (Service Management, 2020)


fig. 2.5. ICE Emma (ICE, 2022a)

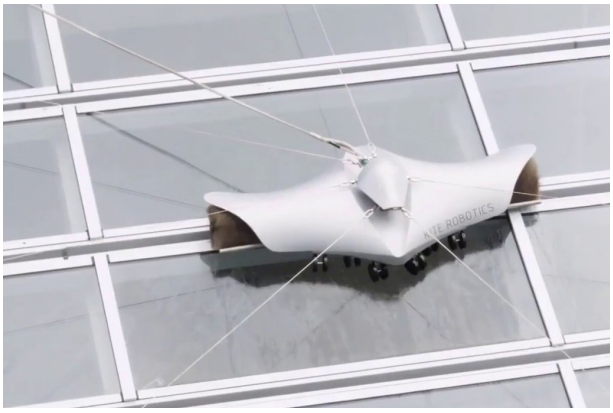

fig. 2.6. Kite robot (KITE Robotics, 2021)

The Kite robot (figure 2.6.) is a robot specialised for the cleaning of exterior windows for large building, developed by KITE Robotics (2022). The main goal of the robot is to reduce the need for human window cleaners for large building such as skyscrapers, since this is often a costly, slow, and dangerous process. The robot is attached at the outside of the building, and can move in a set cleaning pattern horizontally and vertically using cables. The windows are cleaned through the robot's rotating brush. The robot can clean either automatically with a pre-programmed route, or manually by an operator through a control panel.

Electronic tool company Makita developed its own commercial and industrial variant to existing domestic vacuuming robots, with its Robocleaner (Makita, 2022) (figure 2.7.). The robot has a set of three brushes that can pick up general litter, as well as a built-in vacuum for dust and fine parts. Using sensors, it can detect obstacles and ridges to avoid. Floor markers can indicate the area that must be cleaned. It can operate autonomously to seek its own path, or by a human operator using remote control.

The Liberty series of autonomous floor scrubber-drier robots (figure 2.8.) was developed by Nilfisk (2022). The robots are designed for large spaces, and can automatically generate suitable cleaning paths to follow. The robot informs the operator when it is finished with its current tasks, or in case of issues that need resolving manually. Floors are scrubbed using brushes. Newer models can also use UV-C light to disinfect floors and specifically destroy pathogens, a technology that was developed in response to the Covid-19 pandemic.

Cleaning company Vlietstra and cleaning technology company HW Reinigingstechniek collaborated on the development of a robot called Magntrac (figure 2.9.), specifically designed for the cleaning of wind turbines (Clean Totaal, 2015; Pil, 2014; Service Management, 2020). The robot can move on the turbine towers using magnets and


fig. 2.7. Makita Robocleaner (Makita, 2022)

fig. 2.8. Nilfisk Liberty (Nilfisk, 2022)

fig. 2.9. Magntrac (Clean Totaal, 2015)

tracks, cleaning along its path using brushes and soap. The main goal is to reduce the time and financial costs for the specialised cleaning of turbines, particularly in response to accidental leakages of mechanical fluids. The robot is furthermore equipped with cameras, which allows the operator to check where the robot is moving, where cleaning is needed, and whether the cleaning is successful.

## Cleaning robotics industry trends

Considering the selection of robots that are currently available, or being developed, certain trends are visible towards particular tasks that get automated, and particular roles and appearance that are given to the robots. As indicated by the market review, the most common tasks that are focussed on regard floor cleaning, such as scrubbing and vacuuming. This is because these tasks generally involve physically stressful and largely repetitive actions from human cleaners, as well as being relatively easy to automate with a consistent routine of actions that a robot could follow. Nonetheless, there are also other cleaning robots specialised for alternative specific niches of cleaning tasks, such as the Kite robot for large window cleaning, and the Magntrac robot for wind turbines. There are also robots such as the Care-O-bot that incorporate a wide variety of cleaning features. The nature and variety of tasks that are assigned to a robot will impact the role that a robot will take on, as well as how the work experience of the human cleaners is affected. A robot that is specialised towards a small set of specific tasks will likely be akin to a subordinate or tool to the human, taking over the mundane or stressful tasks to give the human opportunities to focus on more satisfying parts of their job. On the other hand, a robot with a wider variety of functions, potentially some social, could be more like a colleague and autonomous collaborator to the human, as they work together as a team to more effectively fulfil the clients' cleaning requirements.

With regards to visual design and personality, there are a variety of approaches visible in the market. Machines like those of Cleanfix, TASKI, and Nilfisk are more mechanical and functionalist in approach, being aimed at task optimisation and efficiency. By contrast, the Annie Trash robot of Hago is more socially oriented, being aimed at changing people's behaviour, as well as being endowed through visual and audible elements with a friendly expressive personality. The cleaning robot based on Fraunhofer's Care-O-bot platform possesses elements of anthropomorphisation, in its overall form as well as the use of a robotic arm. This gives it a more organic and expressive form that can elicit liking from humans around it. A contributing factor to this is however that the Care-O-bot platform was originally developed for the purpose of social robotics in healthcare. There is thereby a range visible in the market of whether a robot's appearance is designed as functionalistic or as expressive and sociable, through anthropomorphised or animal-like elements. This appearance will similarly to the robots' functions affect the work of human cleaners. The robots with a mechanical and functional appearance will become more akin to tools for the cleaners, enhancing their effectiveness and competence at fulfilling their tasks. The more expressively oriented robots on the other hand may also fulfil certain needs for relatedness and social interaction for humans in the environment, including the cleaners but also for example other users of the cleaned space and visitors.

A mapping of the discussed robots along the axes of functional variety and appearance can be found in figure 2.10.

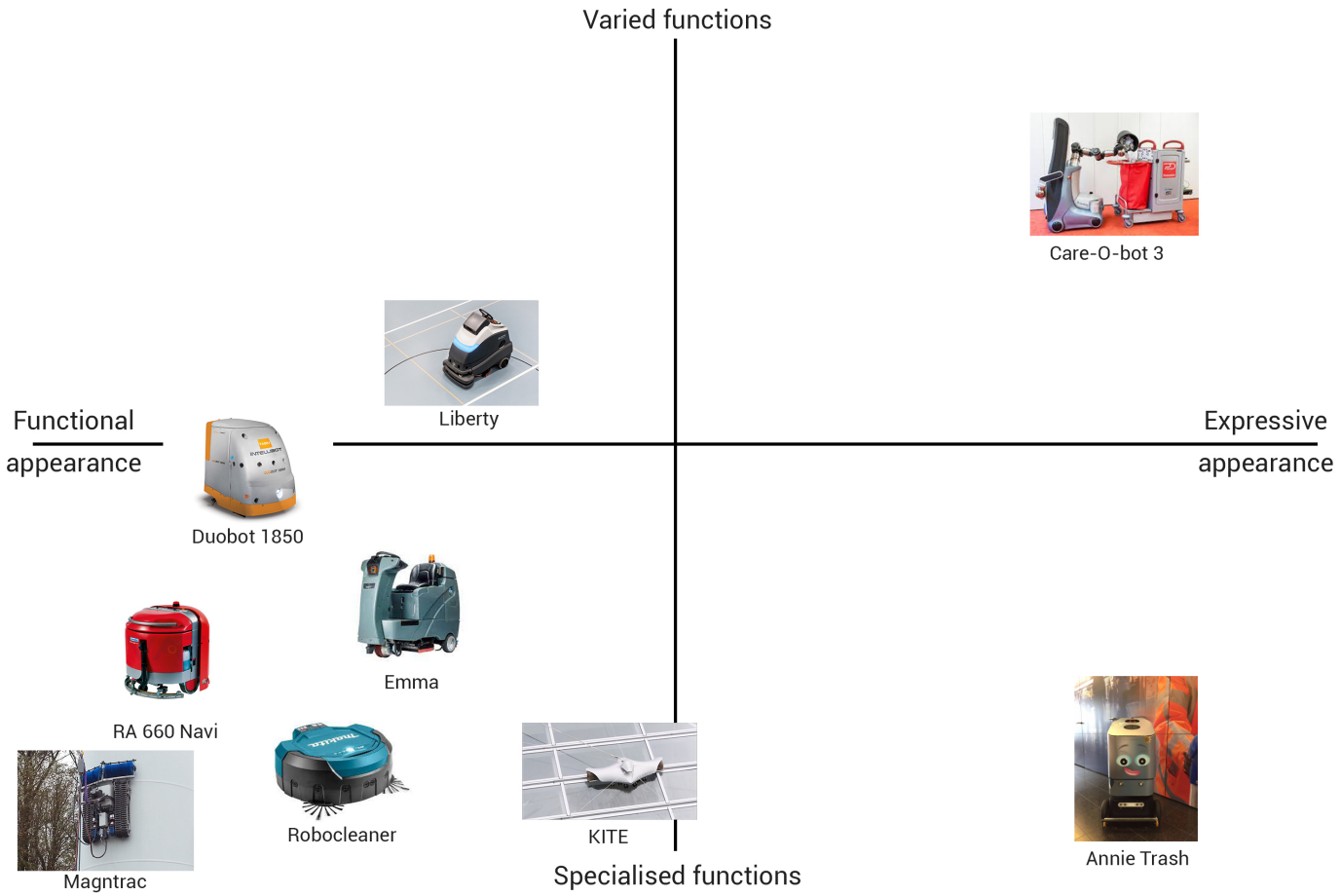


fig. 2.10. Market study mapping

## 2.3. Human-robot interaction and collaboration

There has been extensive previous research in the fields of human-robot relations, and more specifically the relations between robots and labour and the impact of robots on various aspects of work in general. The following section will provide a review of selected literature on human-robot relations and robots and work, to determine themes to account for in the responsible design and implementation of work robotisation.

### Human-robot relations

As humans interact with increasingly advanced forms of robot technologies, they will start to form relationships with those robots. Previous research has studied the mental models involved in these relationships, as well as the ethical concerns and dilemmas that arise as a result of them. Robots can take on increasingly social roles and status as they become more autonomous, also driven by for example processes of anthropomorphisation, and they can thereby become active social agents that influence their social environment.

#### Robot mental models

The overall nature that relationships between humans and robots take, from a narrative standpoint, has been studied by Payr (2019). People's attitudes towards robots are influenced by their pre-existing mental models, which means that fictional and non-fictional representations of robots can impact how real robots are perceived. Examples include the cultural notions of the Three Laws of Robotics that were formulated by the science-fiction author Isaac Asimov to theorise how robots could be integrated into a suitable role in society that is acceptable to humanity. Initial depictions of intelligent robots in visual media such as films were often humanoid in size and shape, as a result of those 'robots'

being in fact humans in costumes. These early depictions likely still affect modern cultural perceptions of what an advanced robot ought to look like, furthermore influenced by conceptions around anthropomorphism. A large portion of fiction analysed by Payr (2019) furthermore focusses on robots in the role of 'pets' or 'companions,' thereby subservient to human masters rather than autonomous agents like 'androids.'

Even non-fictional robots are mostly familiar to the public through promotional and documentary videos, thereby giving them a fictional component as video-makers create a narrative about human-robot relations. These depictions can at times exaggerate or misrepresent factors such as autonomy or intelligence of the robot that is shown. This can lead to misunderstanding, disappoint, and rejection from end-users when the robot is unable to meet their expectations. Moreover, Payr (2019) raises that the common depiction of robots as 'pets' that are subservient to human will can often be difficult to reconcile with the real-life role that might be assigned to that type of robot. There are envisioned roles for companion robots as caregivers in eldercare or tutors in education, which are roles that require activity rather than passivity and can involve having to challenge and criticise the human partner. Similarly, for a work-context such as professional cleaning, it might be necessary for a cleaning robot to take a more active and dominant role in the relationship with its human operator, in order for the work to be done effectively and safely.

**Ethical concerns of human-robot interaction**

De Graaf (2016) discusses the social and ethical issues of socially interactive robots, and their envisioned role in the lives of humans. A social robot should ideally be capable of communicating in such a way that users can understand the robot in human social terms, allowing them to relate to and empathise with the robot.

The question then arises whether human-robot relationships can be a desirable contributor to the philosophical concept of the good life, that is to say the most desirable life that optimises the wellbeing of people. It appears feasible, according to De Graaf (2016), that humans could establish close social relationships with robots, and could also benefit from those relationships, as long as they are aware that a robot's social standing will inherently be artificial with an illusory moral standing as a social agent. In such instances, the establishment of such relationships is argued to be morally acceptable. However, such relationships should not go on to replace a person's arguably more valuable human relationships, and there is an apparent risk that interacting too deeply with robots could build a problematic mental model in users of what a social relationship should look like.

The relationships that De Graaf (2016) discusses are primarily deep bonds such as friendship. Nonetheless, it is reasonable to assume that both the benefits and risks of such human-robot interactions will similarly be present in more professional work context, such as the present case of cleaning work. The viability of building a colleague-relationship between human and robot workers will be discussed more extensively later in this section.

**Robots as social agents**

In studies by Forlizzi (2007) and by Fink, Bauwens, Kaplan, and Dillenbourg (2013), the social integration of vacuuming robots in domestic contexts was ethnographically explored. Forlizzi (2007) provided families with either a vacuuming robot or a stick vacuum, and compared the effects of either technology on cleaning behaviours, as well as the social characteristics that were attributed to the technologies. It was found that integration of the robots changed family dynamics, with different people becoming responsible for cleaning the house as well as changing how the cleaning was done, namely through use of the robot. The robots moreover took on a social role, inspiring interaction from users to watch them or play with them. Some users also assigned social attributes to the robot itself, such as giving it a personal name talking to it.

Fink et al. (2013) conducted a similar study, wherein they placed vacuum robots in the homes of participants to explore the integration of the robots into daily practices and the social environment. They similarly found that users attributed human personality traits to the robot, noting that this was despite the robot having a non-humanoid form. They do however theorize that the social attributions and social agent role that was given to the robot could represent a short-term effect due to novelty, and thus become less significant when people become used to the robot. They for example found that over time, the robots' perceived identity from the users changed from being a fancy robot to being merely a cleaning tool. It will be notable to consider how these results in domestic (cleaning) contexts could compare to the integration of robots into a professional work context.

### Social roles of robots

Dautenhahn et al. (2005) studied through questionnaires and trials the social roles that humans would assign to robots they interact with. The focus of their study was on robots in a domestic context, and based on participants' assessment of what role they believed a future companion robot should have in the home. As part of the experiment, participants interacted with a human-sized non-humanoid robot in a simulated living room to fulfil various tasks and scenarios. The majority of participants envisioned a robot as an assistant, or a machine or appliance, with a large section also considering the role of servant for the robot. A friendship relationship was deemed as less suitable. It was deemed that a robot should be predictable in its behaviour, as well as polite or even subservient towards the human user. Participants indicated a preference for the robot using human-like communication, such as speech and gestures, but deemed it less important for it to exhibit human-like behaviour and appearance. For the case of designing cleaning robots, it would hence be advisable to incorporate polite and predictable behaviour into the design of cleaning robots, as well considering the possibilities for human-like communication.

## Robots and work

While the previous section explored themes and concerns related to human-robot relationships in general, there are specific issues that arise with robots being implemented in work environments. There are expected trends and perceptions for how robotisation will look in various industries, including cleaning. Work robotisation will require effective integration of a robot into the (social) environment and practices of the respective occupations. Moreover, as humans and robots collaborate on work tasks, there needs to be a suitable allocation of tasks. Robots in workplaces will impact the practices and work experience of workers, as robots become potentially akin to colleagues to humans, and must thereby contribute to human work remaining meaningful and satisfying. It will be particularly important for cleaning robots to address these themes, due to the concerns and challenges for work satisfaction within the industry described earlier in this chapter.

### Public expectations for robotisation of work

In a qualitative study of interviews, Bhargava, Bester, and Bolton (2021) studied the expectations of current and future occupational end-users of robot-, AI-, and automation-technologies. Their participants indicated that since a 'human touch' and decision-making capacity can not be taken over by technology, they expect that it will be particularly low-level jobs that get automated and replaced, whereas high-level jobs such as management will be less affected. Participants felt like they may need to obtain new skills in order to remain employable in the future, as a result of automation. The technologies were expected to enable better use of the workers' time, as routine and menial tasks are taken over from them. While this would support their job satisfaction, this satisfaction can also

be at risk since the technologies are considered unable to build strong interpersonal relationships with the user to fulfil emotional needs. It is suggested that organisations should communicate openly with their workers about the implementation of automation technologies, and involve them in the process, as this will lead to better acceptance. This hence emphasises the need for a collaborative design approach to the development of robots for work.

Studies like those of Bhargava et al. (2021), as well as anecdotal beliefs, raise the notion that innovation trends like robotisation will reduce the employment numbers of low-skilled workers, such as those in cleaning. By contrast, Dixon, Hong, and Wu (2021) suggest that robots will actually increase the overall employment number, and that any reductions in the workforce are mainly at the managerial level. This is supposedly the result of managerial level tasks, such as administration and process scheduling, being easier to (partially) automate, compared to the complex and variable tasks that are done by lower-ranked workers. This does raise ethical concerns about the robots being developed, since if they take over the jobs of managers, this could entail the robots taking on a form of supervisory role over human workers, as the robots give orders and instructions to human employees, and take on a hierarchical role above the humans. Such developments are at least theoretically conceivable in cleaning work, if a robot were to take on tasks of process planning and results evaluation.

**Organisational integration of robots**

A study by Mutlu and Forlizzi (2008) investigated the integration of service robots into workplaces on an organisational level, using the ethnographic case study of different departments in a hospital. The robot used for the experiment moved between the hospital units to deliver for example medicine or food trays. They gathered data on different uses and reactions from workers in the environment, to determine guidelines for the design of suitable robot integrations. Their findings indicate that the perception and use of workplace robots is heavily dependent on the work practices and social relationships of users, and thus impact the organisational integration of the robots. Aspects of workflow, and social, political, and environmental context play an important role. From an engineering perspective, it is suggested that robot designers should account for time-critical characteristics of users' work, to avoid the robot disturbing users at times when they do not wish to be interrupted. They also propose the robot could be designed with features to become a part of the social relationships and interactions between workers, by for example delivering recorded messages alongside the other delivered goods. Overall, they emphasise the need for a value-driven and participatory approach to robot design to achieve desirable outcomes and acceptance from workers. Such a participatory approach would hence also be advisable for the case of cleaning robotisation, by involving cleaning workers as well as other stakeholders in the development and implementation processes.

**Task allocation**

The robotisation of labour will for the foreseeable future require humans and robots to collaborate on tasks (Hinds, Roberts, & Jones, 2004). An important consideration for designing such a collaboration between humans and robots will be the allocation of individual tasks, that is to say determining whether a particular task should be performed by the human or by the robot. This task allocation should be based on the capabilities of the respective agents, assigning tasks to human or robot based on who is most suitable (Ranz, Hummel, & Sihn, 2017). A survey of public opinions conducted by Takayama, Ju, and Nass (2008), indicates that people deem robots most suitable for tasks that require memorization, keen perceptual abilities, and service-orientation. Humans were conversely preferred for tasks of artistry, evaluation, judgement, and diplomacy.

De Winter and Hancock (2015) reached similar results with a survey of perceived robot capabilities compared to humans, based on the Fitts list of machine capabilities (Fitts, 1951). It was judged that robots surpassed humans at simultaneous operations, speed and power, replication, detection, long- and short-term memory, and computation. Their results conversely indicate that humans were deemed to surpass robots at improvisation and inductive reasoning. These results represent the judgements and opinions of humans, rather than reflecting the true capabilities of a specific person or machine, but can nonetheless serve as a basis for considering task allocation.

However, Ranz et al. (2017) point out that there can often exist overlap between the capabilities of humans and robots, where they would both be suitable for a particular tasks. In such instances, aspects such as time efficiency, financial investment, required quality of end results, as well as the quality of work for the human should be taken into account to make a final decision. Particularly the latter factor is of interest for the present study, as it represents the overall work enjoyment and satisfaction of the labourers, in our case cleaning workers.

**Factors for human-robot collaboration**

Hinds et al. (2004) define professional service robots as robots that assist human workers in fulfilling their contracted tasks. Robots can complement the unique abilities of humans, as well as tolerate repetitive and mundane tasks in the long-term. They hypothesise that workplaces in the future will rely more on robots and humans collaborating on tasks, each partner using their particular skills and relying on the other to be fully effective. The robots' interactivity and mobility will mean that they can affect the work environment in socially important ways. Their experiment explored two robot characteristics. They firstly studied the impact that a robot's human-like versus machine-like appearance can have on users' reliance on the robot, as well as their sense of responsibility for the tasks. Second, they studied the variable of 'status' of a robot, by varying whether it was characterised as a supervisor to the user or as a subordinate or peer. Furthermore, there is a potential degree of interaction between these two characteristics, since a more machine-like robot will likely be perceived by users as more like a tool or subordinate rather than a supervisor. The results of their experiments indicate that participants felt less personally responsible for the tasks when collaborating with a human-like robot partner compared to a machine-like robot partner, but they did not necessarily feel more reliant on the human-like robot. They similarly appeared to not be more reliant on a robot that was characterised as a supervisor compared to one characterised as a subordinate or peer. There was mixed support for the hypothesis that participants would feel less responsible for the tasks when collaborating with a robot that had supervisor characteristics compared to one with characteristics of a peer or subordinate.

The quality of the human-robot tasks collaboration can furthermore be dependent on social cues. Terzioğlu, Mutlu, and Şahin (2020) studied the effects of potential social cues, namely the concepts of gaze, arc movements, and secondary breathing actions. According to them, it will be essential to endow collaborative robots with such cues to establish and maintain short- and long-term interaction relationships with their human co-workers. Even without more elaborate social features, such as conversational capacity, the addition of principles like gaze, arcs, and breathing motions can enhance the interactions to be more positive and accepted by the workers. These concepts were chosen by the authors based on principles in animation. Gaze is used as a means of enhancing the appeal of the robot by creating a believable character that humans can engage with, and specifically consisted of giving the study's robot simulated eyes placed on its 'head,' to give it an animal-like appearance and face. With these 'eyes,' the robot

could direct its gaze and thereby the human worker's attention towards points of interest in the environment, or looking directly at the worker themselves to establish a social connection. Arc motions consist of programming the robot to move along smooth and rounded trajectories, rather than in straight lines with rapid sharp corners, which again makes it appear more life-like and natural towards humans. Similarly, the implementation of secondary actions that serve no direct purposes, such as subtle breathing-like motions while the robot is idle, can enhance the life-like appearance. These breathing motions can additionally serve as a means for humans to detect whether the robot is currently in operation and waiting, but therefore still moving, or whether it is turned off and thus completely still. The authors studied the impact of each of these concepts through user studies. They presented participants with tasks to work on collaboratively with a robot wherein the aspects of gaze, motion, and breathing were manipulated as variables, and asked them to answer a questionnaire about their experience and perception of the robot. Their results indicate that particularly the breathing motions and gaze led to an improved experience for the operator, and the various principles can together create a more life-like character for the robot. These concepts could hence act as useful means of improving the social interaction when implementing robots into work environments such as the professional cleaning industry.

**Robots as co-workers**

Strohkorb, Huang, Ramachandran, and Scassellati (2016) describe how supportive human-robot relationships can be established and maintained. According to them, workplace robots are currently advanced in regards to efficiency and precision of their work. These robots however still require integration as co-workers. It is proposed that interaction with humans could for example be improved through the use of nonverbal social signals, and that a robot should aim to adapt to human behaviour rather than expecting the human to change their behaviour to follow stringent operation parameters set for the robot. This can allow for a more fluid and intuitive human-robot collaboration. The authors propose three building blocks for enabling sustained and supportive human-robot relationships. The first building block is the use of *socially intuitive interaction*, which entails a robot firstly being able to express its internal state in a manner that can be intuitively interpreted by humans, and secondly the robot being able to interpret and understand the internal state of humans based on their behaviour, and adjusting its behaviour accordingly. The second building block is providing a *personalised interaction experience*, which will require the robot again being able to perceive and interpret the behaviour and needs of individual humans, and adapt its behaviour accordingly to be personalised for a specific user. The third and final building block is to design for *long-term interaction*, by enabling the robot to interact with users over long periods of time to make a long-lasting influence, and to increase the user's engagement with the robot over time. These building blocks could be integrated in the design process of future cleaning robots to improve integration as co-workers to human cleaners.

Work satisfaction is dependent on workers having good colleagues. In accordance, for a robot to improve the working experience of humans, it could be designed and integrated so that it can act as such a good colleague. The question can arise whether a robot is in principle even capable of being a good colleague to humans. Nyholm and Smids (2020) have explored this question. They firstly posit that, comparatively speaking, it will at least be 'easier' for a robot to be a good colleague than it would be for a robot to be a good friend or a loving romantic partner, that is to say domains where applicability and morality of robot relationships have been quite debatable (cf. De Graaf, 2016; Weijers, 2013). Nyholm and Smids (2020) define a list of aspects that would make an actor, human or

robot, a good colleague, and posit that robots would at least in theory be able to meet nearly all requirements. The greatest challenge for good collegiality by robots is that they would need to have a capacity for socialising in a collegial, respectful, and friendly manner. It is debatable whether a robot colleague could meet this threshold. That said, as was discussed by De Graaf (2016), there is potential under the right conditions, for humans to form a strong social bond with robot counterparts, which could enable them to meet this requirement set by Nyholm and Smids (2020). This potential for good collegiality would then also be viable for cleaning robots to achieve and thereby lead to a more satisfying work environment for the human cleaners.

The arguments of Nyholm and Smids (2020) can be somewhat contrasted with the comparatively more critical comments of Groom and Nass (2007), regarding robots' capacity for being full-fledged teammates in human-robot teams. Amongst humans, team memberships can improve communication, trust, effort, and commitment, and allows for focussing on similarities over differences. It can also induce a sense of shared identity, and more positive perceptions of fellow team members. In past attempts at incorporating animals into human teams, it was found to be comparatively more effective to have the animal's 'handler' as a team member rather than the animal being a team member in itself. They expect that similar results could arise for robots being implemented into teams, with for example a robot's operator becoming a team member rather than the robot itself. Within their conception, human teams are partly reliant on the members sharing a (human) mental model. This would mean that to be accepted by humans, robot team members would need to exhibit a similar degree of 'humanness,' which could prove challenging if not impossible. Successful teammates moreover need to be able to subjugate their own individual needs for the needs of the group, but robots have no individual needs to be subjugated. Overall, robots are unable to meet the expectations of humans for social cues and capabilities. What these issues add up to is that robots would not be able to act as true teammates to humans. Rather, according to Groom and Nass (2007), an alternative relational structure would be needed that exploits the individual strengths of humans and robots. Such a relational structure would hence need to be found to facilitate an effective integration of cleaning robots into workplaces. For determining these structures, it may be worthwhile considering again the findings of Dautenhahn et al. (2005) and Hinds et al. (2004).

**Trust in robots co-workers**

For both Nyholm and Smids (2020) and Groom and Nass (2007), an important facilitating factor for human-robot work collaboration is the trust that is established between user and machine. Lyons, Wynne, Mahoney, and Roebke (2019) performed a qualitative study to determine key aspects that influence the trust process in human-robot teams. They define trust as one's willingness to be vulnerable to the actions of another agent, in this case a robot. The study defines a set of trust antecedents that impact human users' willingness to trust a machine teammate: *Reliability, Predictability, Helping to solve a problem, Proactively helping a person, Transparency of decision logic, Transparency of intent, Transparency of state, Liking, Familiarity,* and *Social interaction*. They go on to conceptualise a metric for 'autonomous agent teammate-likeness,' which Wynne and Lyons (2018) previously defined as "the extent to which a human operator perceives and identifies an autonomous, intelligent agent partner as a highly altruistic, benevolent, interdependent, emotive, communicative and synchronized agent teammate, rather than simply an instrumental tool" (p. 355).

To briefly contrast this with other authors' ideas and conceptualisations of trust in human-robot relationships, Payr (2019) observed in their exploration of robot narratives in fiction

that filmmakers perceived old and well-used (and small) robots as more trustworthy and innocuous than (big) shiny new ones. According to experiments performed by Biermann, Brauner, and Ziefle (2021), the contextual work environment as well as the designed physical appearance of a robot are key contributors to the trust perceptions of workers.

Coeckelbergh (2012) provides an alternative interpretation of the construct of 'trust,' defining that when humans describe their trust in a technology, they are referring to their expectation that the technology will function and do what it is meant to do to attain the goals set by the users. There is then also an underlying reliance on trust in the humans that were involved with the technology, such as the designers fulfilling their duties to design an adequate product and other users of the technology using it properly. In Coeckelbergh's (2012) conceptualisation of trust, there are three conditions that must be met for trust to be possible. First, both agents need to be capable of expressing a moral language of trust that entails promise making and the expression of expectations. Second, there must be freedom and uncertainty within the interaction, with the trustor needing to be free in giving trust as this can not be forced, and the trustee being free to have the possibility of having the received trust be misused, since if trust could not be hypothetically misused there is no uncertainty and hence no need for trusting. Third, there needs to be an existing social relationship between the agents, where participants experience themselves as vulnerable in relation to each other. According to Coeckelbergh (2012), robots are unable to truly meet all three conditions, but they can superficially appear to do so, which can create a kind of virtual trust. These considerations and conceptualisations of trust will need to be explored more deeply within the design of future cleaning robots, as trust can be expected to be an important value to meet for integration and acceptance of the robots by cleaning workers.

**Impact of robots on meaningful work**

On the topic of robots' impact on daily work life, Smids, Nyholm, and Berkers (2020) have explored the effect that the implementation of robots into workplaces can be expected to have on workers' experience of their work being meaningful (cf. Berkers, Smids, Nyholm, & Le Blanc, 2020). They define five characteristics of meaningful work, which could be threatened or given opportunities by robots: *Pursuing a purpose*, which is threatened if robots take over the most challenging and worthwhile tasks, but an opportunity is when the human and robot form a team that collaboratively achieves better outcomes; *Social relationships*, which is threatened if most human teammates are replaced by robots, but an opportunity is if the robots are endowed with social interaction capabilities or designed to take over impersonal tasks so the human can focus on socially salient parts of their work; *Exercising skills and self-development*, which is threatened if robots take over complex and challenging tasks, but an opportunity is when the robots can enable the worker to acquire new skills such as advanced robot operation; *Self-esteem and recognition*, which is threatened if the human is relegated to merely operating and supervising without being recognized for their work, but an opportunity is if their social environment were to actively acknowledge and praise their skills as for example the operator of the robot; *Autonomy*, which is threatened if the robots require the human to work according to strict protocols and restrictive rules, but an opportunity is if the workplace is redesigned to leave room for autonomous human action. These characteristics show overlap with the core needs for personal wellbeing defined by self-determination theory (SDT) (Deci & Ryan, 2012; Ryan, 2009), which will be explored further in chapter 3 of this thesis.

From the discussion of possibilities for robots by Smids et al. (2020), it becomes apparent that the implementation of robots in the workplace could be both beneficial or detrimental for workers' experience of meaningful work, and it will be dependent on the proper design

and organisational integration of the robots to achieve a desirable outcome. For cleaning robotisation, it will be important to achieve an implementation of the technology that supports the meaningfulness of the work for human cleaners, to more adequately meet the industry's challenges discussed earlier in this chapter.

As part of humans' work being meaningful, it is important for them to perceive their contributions and labour as valuable achievements. Danaher and Nyholm (2021) explore this specific aspect through the impact of AI and automation on humans' sense of achievement. Feeling a sense of achievement is a key value for meaningful work, but the introduction of innovations can lead to a supposed achievement gap. This would mean humans being unable to compete with the performances of machines or being otherwise unable to satisfy the set conditions for (perceived) personal achievement. Automation, which robotisation forms a part of, can compromise workers' sense of achievement even in instances where the workers are not fully replaced and will work collaboratively with machines, as is expected to be the case for the cleaning industry. Automation could for example place workers in more peripheral positions, such as maintenance of the machines, where their direct contributions to producing an end result, such as a cleaner environment, are diminished. Workers become unable to claim a direct causal role in the results of their work, as the machines sever the connection between the workers and their output. They also reiterate, similar to Smids et al. (2020), that automation can narrow workers' ability to choose their own approach, as they are instructed to work within the parameters of the machines.

To mitigate their stated risks, Danaher and Nyholm (2021) offer suggestions for workplace policy. It is for example possible to accept the loss of achievement in work, but to emphasise in response other components of work that can be considered meaningful for the workers. Alternatively, a means could be sought to maintain a distinct human touch to the final results of the collaborative work, for example in the case of cleaning robotisation by having workers apply the final polish to the environment that makes it feel truly clean. Another option is for the workplace to emphasise the role of teamwork in producing outputs, thereby reframing the situation to considering the end results as the collaborative achievement of human and machine. Finally, it may be possible for workers to seek alternative sources for achievement outside their work, as improvements in work efficiency could hopefully enable them to dedicate time to for example hobbies or family. These strategies could be viable to maintain the desirable level of achievement and meaningfulness throughout the process of automation and robotisation in industries such as cleaning.

## 2.4. Discussion

The preceding has provided a review of circumstances within the cleaning industry, the state of art in the market of cleaning robots, and the available theory in literature on the general concepts of human-robot relations and impact of robotisation on work. This review indicated that it will be necessary to account for the sociotechnical values that are at stake when considering the robotisation process in the cleaning industry specifically. Current design approaches for cleaning robot products appear to not explicitly account for these sociotechnical values, which can lead to products being implemented that do not adequately address the challenges of cleaning work.

Schwartz (2012) developed a theory of basic values, considering them as the underlying motivations and beliefs that drive humans' actions and behaviours. The Value Circle of Schwartz (2012) acts as a framework consisting of ten main overarching values that can

drive humans' actions, as well as the ways in which those values can be aligned or in conflict. The overarching main values can be seen as each encompassing a group of more specific sub-values that can play an important role in people's lives. Based on Van de Poel and Royakkers (2011), values can be understood as strongly held beliefs about general goals worth striving for in order to attain a good life, and as the underlying beliefs that motivate human behaviour and decision-making. Addressing the challenges of the cleaning industry's robotisation will demand a design approach that is sensitive to these values, such as the approaches proposed by value-sensitive design (VSD) (Friedman, Kahn, & Borning, 2002).

The background review presented in this chapter has already introduced a range of values that are at stake and should be accounted for in such a value-centred design approach. Based on the conditions and challenges inherent to the current professional cleaning industry, values that will be of importance include physical and mental health, potential for growth and ambition, and respect and recognition from others. The review of current cleaning robot products and apparent market trends indicated that through functionality and appearance, a robot can be assigned various social roles, and affect their work enjoyment, cleaning effectiveness, and social engagement. Finally, through the existing literature on human-robot interaction and robotisation of work, values like sociability, collegiality, and meaningfulness of work are introduced as at stake. This selection of values and themes should hence be addressed in the design and implementation process of future cleaning robotisation.

## 2.5. Conclusions

This chapter explored the general context of cleaning work, the current market for robotisation in the professional cleaning industry, as well as the existing theory on human-robot relationships and robots as colleagues in work. The basic business characteristics and demographics of the Dutch cleaning industry have been discussed. Cleaning work can strain both the physical and mental health of its workers, which represent the main challenges that robotisation is generally meant to address. There is moreover a stigma of dirty work connected to the cleaning industry in its public perception, that can lead to a sense of objectification and loss of dignity on the part of cleaning workers. There is similarly a lack of visibility and recognition for cleaning workers. These are issues that robotisation could improve upon, or should at least avoid exacerbating.

A review of existing cleaning robot products has indicated that the main focus of current robotisation appears to be on floor cleaning tasks, though specialised products also exist for alternative specific cleaning uses. Existing robots predominantly take a specialised approach, wherein their functions focus on fulfilment of a small range of specific cleaning tasks. Nonetheless, there exist certain robots that incorporate a more varied set of cleaning features, which impacts the type of human-robot collaboration that is created, and the sociotechnical values that are affected. There are moreover various approaches and extents to which cleaning robots have been endowed with social features and expressive personalities and appearances. Many robots take a function-oriented approach, acting akin to intelligent tools. There are however also concepts for socially-oriented robots that aim at either behavioural change by humans, or to take on an assistant or colleague role to a human operator.

A review of literature in human-robot relationships indicates that the social capabilities of robots will play an important role for the interactions with the technology and the willingness of humans to accept the robots in their lives. The robot needs to live up to

their expectations. Through interaction, users can end up assigning humanoid traits to robots. There are risks and benefits to the establishing of close bonds between humans and robots, and there are various roles that a robot can take towards the human, though it appears that assistive subordinate roles are considered most suitable.

Based on the literature, the implementation of robots can affect work on multiple facets of job satisfaction, with discussion existing on which occupations are most at risk of automation. Since humans and robots will be collaborating at work, task allocation becomes an essential factor to consider. Robots will need to be adaptive to human behaviour to be accepted as colleagues, and need to be designed to enhance rather than hinder the meaningfulness of the work experience. By supporting the workers' sense of achievement, and becoming a good and trustworthy colleague to the human, robots can be designed to improve the working life of people, but it will be necessary to overcome the apparent risks and challenges to that work satisfaction and enjoyment, and to align with the values of the workers through a collaborative design process.

Current cleaning robot design practices appeared to lack this type of collaborative and value-based approach. To address this, the results of the topics reviewed in this chapter should be incorporated into a value-centred design approach that aims towards responsible and desirable outcomes to cleaning robotisation. The theory and literature discussed have provided a first overview of values and themes to account for when designing and implementing future cleaning robots. These themes however do not yet fully address the practical and daily experiences of cleaning workers and other stakeholders of cleaning industry, and the values they deem personally important to design for in robotisation. This will hence be addressed through empirical research conducted with industry stakeholders, in the next chapter, as well as the development of dedicated participatory design tools for cleaning robotisation throughout the research in this thesis.

# 3. Exploring cleaning industry values through a stakeholder workshop

*The following chapter was originally written as an independent research paper, which was presented at the Philosophy of Human-Technology Relations conference 2022[1]. It concerns the planning and execution of a stakeholder workshop with participants from within the Dutch professional cleaning industry. The previous chapter explored the concerns within cleaning work, as well as the (expected) impact of robotisation on the work from a theoretical standpoint, based on industry reports and academic literature. It was found that there is a lack of consideration for value-based concerns, regarding the impact that robotisation will have on cleaning work. To address this, the following chapter explores these themes from the practical perspective of industry stakeholders, to gather bottom-up data about the challenges that must be addressed within the industry, how it is envisioned that the industry should look in the future, and the values that are at stake with regards to robotisation.*

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Various industries and occupations are currently undergoing a transition in which human labour is being replaced and enhanced through the introduction of robots. Kencebay (2020) estimates a market of 2.4 million robots in manufacturing, with predictions that by 2022 there could be 2 million new industrial robots added to the workforce worldwide. These trends have also raised concerns for potential human employment losses, with many occupations predicted to be viable for (partial) robotisation of tasks that were previously done by humans (Frey & Osborne, 2013). On the other hand, there is also potential that rather than being a threat to work satisfaction and wellbeing, robots can make work more interesting and more in line with human needs and values.

One industry currently investigating the potential for robotisation is professional cleaning, where robots are being developed to take over tasks from human cleaning workers. Introducing robots into any work environment will for the foreseeable future require them to work alongside human workers as part of human-robot teams, with tasks being assigned either to the human or the robot based on suitability and preference (Groom & Nass, 2007; Hinds et al., 2004). Factors for suitability include for example repetitive and physical tasks being assigned to robots, whereas creative and holistic evaluation tasks, such as planning a suitable approach to cleaning and interpreting the needs of clients, are assigned to the human. In the cleaning industry, aspects including repetitiveness and physical demands posed by cleaning tasks are key antecedents of the transition towards robotisation, as these features put both a bodily and mental strain on human workers (Kirov & Ramioul, 2014; Søgaard et al., 2006). To address these issues, robotic products have been introduced to the market such as automated scrubber driers, which can navigate assigned routes semi-autonomously and clean large floor areas (cf. Diversey, 2021). Study of the robotisation of cleaning has taken on additional relevance due to the Covid19 pandemic, which has placed additional importance on the value of hygiene, while however also leading to pressure for human workers to only travel to workplaces when truly necessary.

Importantly, the introduction of robots will have consequences for the nature of cleaning and the working life of cleaning workers. Examples include the effect of robotisation on work satisfaction (Bhargava et al., 2021), workers' perception of their labour as being meaningful (Berkers et al., 2020; Smids et al., 2020), and the social objectification of stigmatised work such as cleaning (Terskova & Agadullina, 2019). This raises concerns

[1] Raub, T., Van Rompay, T.J.L., & Verbeek, P.P.C.C. (2022) *Impact of robotisation on wellbeing needs in the professional cleaning industry*

on how in a context of robotisation, human cleaning work can be designed through job crafting (cf. Demerouti, 2014) in accordance with worker values. Achieving a responsible and acceptable implementation of cleaning robots that enhances the wellbeing of human beings in the industry demands study of the impact of robots, the future vision for a better cleaning industry, and the social and ethical values that are at stake.

Van de Poel and Royakkers (2011) define values as: “Lasting convictions or matters that people feel should be strived for in general and not just for themselves to be able to lead a good life or to realize a just society” (p.72). Examples include freedom, satisfaction, and physical wellbeing. Schwartz (2012) conceptualises values similarly as beliefs and motivating goals, that transcend specific actions and situations, and act as standards. Humans will order values relative to each other based on what they deem most important in life, and it is that ordering that drives their actions and behaviours. The Value Circle of Schwartz (2012) acts as a framework consisting of ten main overarching values that can drive humans’ actions, as well as the ways in which those values can be aligned or in conflict. The overarching main values can be seen as each encompassing a group of more specific sub-values that can play an important role in people’s lives. It is such values that are at stake of being impacted or changed by the introduction of new technologies, such as advanced robotics. Studying the values in cleaning work requires a bottom-up approach, wherein the practical insights and requirements from professionals in the cleaning industry take a leading role.

From a job satisfaction perspective, robotisation should ultimately increase autonomy, competence and relatedness. These are generalised basic values for wellbeing in work as proposed by self-determination theory (SDT) (Deci & Ryan, 2012). It could moreover be relevant to study how these general needs interact with and relate to the specific values at stake in professional cleaning work, and the specific context of workers in cleaning. Based on this, it can be determined whether SDT can serve as a suitable framework for studying values in professional cleaning work and its robotisation.

To this end, the following article reports on a workshop in which the visions for future cleaning and the impact on worker values were studied. It will first provide a review of both the technology of cleaning robotisation, as well as the basic wellbeing needs introduced by SDT. The vision for improvement within the cleaning industry through robotisation, as well as the values at stake, are studied through a workshop. The workshop involved professionals from the cleaning industry. The results are discussed through the lens of SDT, to explore the impact of robotisation on the basic psychological needs for worker wellbeing. Finally, a theoretical framework is derived that supports the design and implementation of future cleaning robots to positively contribute to making cleaning work match the potential and aspirations of workers.

## 3.1. Background and theoretical frameworks

To understand and discuss the impact of robotisation within the cleaning industry, we must explore the current state of cleaning work and the currently available technology within the industry, as well as anticipated future trends in robotics design. The following section will therefore start with a discussion on the nature of cleaning work. This is followed by an overview of the technological perspective on cleaning robotisation, including current products, future developments, and existing theory on human-robot colleague relations. Subsequently, a literature review is presented that focuses on needs and values for worker wellbeing, centred on the fundamental values for wellbeing introduced by SDT.

## Characteristics of cleaning work

The professional cleaning sector involves a high amount of heavy physical labour. This has its impact on the physical wellbeing of its workers. Cleaning workers have been found to suffer health risks including stress on the cardiovascular and musculoskeletal systems (Søgaard et al., 2006). The muscle load for cleaning tasks appears to be comparable to the load placed on repetitive machine-based workers. However, cleaning of floors in particular can lead to overall more stress being placed on shoulder muscles than in machine-based tasks. These risks are factors in the development of shoulder and neck disorders in longtime cleaning workers. Søgaard et al. (2006) furthermore point out that the cardiovascular load on cleaners can lead to heart and circulatory system stress that exceeds guidelines set by various labour institutions, at least at the time of their study. The oftentimes monotonous and repetitive nature of cleaning tasks, such as the repeating motions involved in scrubbing floors, moreover places stress on the mental wellbeing of cleaning workers. Such repetitiveness and stress can challenge workers' abilities to find meaning in their work (Isaksen, 2000). This can thereby also lower the work satisfaction of cleaners (Rothausen & Henderson, 2019; Spector, 1997). Hence, the nature of cleaning work impacts both the physical and the mental wellbeing of human cleaning workers.

Apart from intrinsic job characteristics, public perceptions of cleaning work can endanger the work satisfaction and wellbeing of workers. Cleaning work falls within the category of dirty work. Dirty work consists of tasks and occupations that are likely to be perceived as disgusting and degrading (Ashforth & Kreiner, 1999). The groups that these tasks are delegated to are often stigmatised, as the workers themselves become associated with dirt. Within the categories of dirty work that Ashforth and Kreiner (1999) describe, cleaning work can be considered to be physically tainted, due to its extensive contact with dirty environments. However, there is also a degree of social taint involved, due to the often quite servile role that is projected onto cleaning workers within certain organisations. Contact with physical dirt can lead to a detrimental impact on the values of dignity in work, which is for example felt through dismissive behaviour by the public and societal stereotypes of workers having low intelligence (Hamilton et al., 2019). Regarding the dismissiveness by others, Rabelo and Mahalingam (2019) have explored how dirty work occupations can become 'invisible,' that is to say unrecognized or taken for granted (cf. Vlasses, 1997). In their study of cleaning workers' experiences of invisibility, they found that workers' basic need for inclusion and belonging are threatened when their contributions are undervalued. This can in turn have an impact on the experienced meaningfulness of their work. Cleaners that felt invisible at work reported feelings of shame, anxiety, and resignation, which are important values in line with the definition by Van de Poel and Royakkers (2011). Furthermore, according to Terskova and Agadullina (2019), an association with dirty work can cause workers to become dehumanized and objectified. Objectification occurs when workers are perceived as equivalent to objects, which is most likely with dirty work occupations that can partially be done by machines, as would be the case for cleaning work when robots are introduced.

It could at this stage prove worthwhile to also shortly take into consideration how recent events in the form of the Covid-19 pandemic may have impacted the public perception of dirty work occupations. The development of the pandemic and the associated risks for infection has led to a greater social significance of hygiene and cleanliness, which could raise perceived value attributed to occupations like cleaning work. The pandemic has turned some stigmatized sectors into essential services, labelling their workers as equivalent to heroes (Mejia et al., 2021). However, according to Ashforth (2020), while the public regard of certain professions like doctors has improved as a consequence of

Covid-19, this is less pronounced for professions that are tainted by dirty work. This gets attributed to those occupations being generally less public-facing, and hence less visible for the general public. This line of reasoning is in line with the aforementioned issue of work invisibility. Hence it remains questionable whether the effects of the pandemic have had a positive or negative impact on the values important to work within the cleaning industry.

## Technological development in cleaning robotisation

At time of writing, there are various cleaning robot products that have been introduced to the professional cleaning market or are currently undergoing conceptual development. Current robots notably display differing approaches with regards to aspects such as social interaction and 'humanness' in their design. The Taski Swingobot (Diversey, 2021) can for example be considered somewhat traditional in form and function (figure 3.1a). The robot is designed to scrub floors and vacuum, navigating autonomously along pre-programmed routes and avoiding collision with obstacles and humans using sensors. To illustrate an alternative approach, Bormann et al. (2015) adapted the Fraunhofer Institute Care-O-bot 3 robotics platform to conceptualise a fully autonomous cleaning robot (figure 3.1b). Their robot can fulfil various cleaning tasks using flexible attachments for its robotic arm, and can plan its own efficient route through map segmentation. It is also capable of measuring whether a particular space requires cleaning using sensors that detect dirt and trash. As a final example, the robotics company LionsBot (2020) developed a family of cleaning robots named LeoBots, which can act not only as specialised independent cleaning workers but also as socially embedded colleagues (figure 3.1c). The robots can work together forming a team amongst themselves, which is overseen by a human cleaner supervisor. They are endowed with expressions using simulated eyes and have an audible voice that allows them to speak with humans, with the aim of giving them a friendly personality. This personality is meant to not only support their primary cleaning roles, but also extends to the social domain where they can for instance function as a host for the building that is being cleaned, allowing for a greater sense of belonging and relatedness for people within the environment.

fig. 3.1. (a)Taski Swingobot (Diversey, 2021) (b) Care-O-bot 3 Robot Cleaner (Bormann et al., 2015) (c) LeoBot Scrub (LionsBot, 2020)

The cleaning robots described above are largely oriented towards reducing the workload of human cleaning workers. As robots become more advanced, it becomes possible to bestow them with social capabilities, as has been done to some extent with the aforementioned LeoBots. They thereby become social robots. Within the sociotechnical environment of labour, they can thereby come to act as colleagues taking the form of cobots (Ionescu, 2020; Weiss, Wortmeier, & Kubicek, 2021). Human and robot cleaners will be sharing a workplace, and rely on each other to fulfil their goals and tasks, working together as colleagues (Hinds et al., 2004). Successful collaboration between such colleagues relies on there being trust, in regards to successful performance and social capabilities (Jones & George, 1998; Tolmeijer et al., 2020).

In ethnographic studies in domestic contexts by Forlizzi (2007) and by Fink et al. (2013), the social acceptance of vacuuming robots in people's homes was investigated as well as their role as social agents. Integration of the service robots in the home for example brought changes to family dynamics (Forlizzi, 2007), and elicited anthropomorphization through the attribution of human personality traits to the product despite its non-humanoid form (Fink et al., 2013). Fink et al. (2013) do however hypothesize that such social impacts are reduced as users become more familiar with robots. In a professional context, the inclusion of robots can cause disruptions in workers' workflow and social rejections if not accounted for. To achieve sufficient acceptance it is therefore of importance that designers study the practical as well as sociocultural contexts of users (Mutlu & Forlizzi, 2008). When robots are to be successful members of a team, they may need to take on characteristics of a good colleague to human workers. Robots would then be capable of addressing social values such as collegiality, and a sense of belonging. Nyholm and Smids (2020) have proposed criteria of what would make a good colleague, and assessed whether robots could hypothetically meet those requirements, concluding that robots could potentially come to possess the needed capabilities. The notion of robots becoming members of a team does get challenged by Groom and Nass (2007), since there will always be discrepancies between human mental models and robots' interactions with the world, which can prevent a trusting team relationship.

## Basic needs for wellbeing

In order for people to feel fulfilled and intrinsically motivated in their (working) life, their basic needs for personal wellbeing must be met. Self-determination theory (SDT) defines three intrinsic psychological needs that must be fulfilled for satisfying wellbeing, consisting of autonomy, competence, and relatedness (Deci & Ryan, 2012). Satisfying those needs within a social context allows humans to experience better wellbeing. These basic needs were linked by Gagné and Deci (2005) as important contributing factors for work motivation. Gagné et al. (2015) built a multidimensional scale to measure different types of intrinsic or external work motivation within organisations based on SDT, finding that these aspects are linked across cultures. Van den Broeck, Vansteenkiste, De Witte, Soenens, and Lens (2010) similarly developed a work-related wellbeing scale specifically aimed at measuring satisfaction of SDT's basic needs of autonomy, competence, and relatedness. These existing studies take a fairly general perspective at work within organisations, whereas it can be valuable to distinguish how these concepts can be interpreted and impacted within specific industries, particularly more physically oriented occupations such as professional cleaning. Hence, it is worth exploring how these concepts apply to cleaning work, and how they relate to the more specific sociotechnical values that are at stake as a result of robotisation. The three basic needs introduced by SDT are thus here taken as a generic underlying core of constructs for studying the potential impact of the design of cleaning robots. By defining the basic needs, and more specifically their meaning in cleaning and

connection to specific values, it becomes possible to design products such as robots with design principles aimed at supporting those needs (Peters, Calvo, & Ryan, 2018).

Autonomy can generally be understood as a person's activities and choices being intrinsically motivated, that is to say based on their own interest, investment, and choice, and it has been linked to qualities such as flexibility, volition, and a sense of choice (Deci & Ryan, 2012; Gagné & Deci, 2005). It is hence undermined by what can be considered controlled and extrinsic motivating behavioural factors, such as rewards, regulations, or external demands, which can lead to a sense of being pressured towards particular choices, behaviours, and actions (Ryan, 2009; Vansteenkiste, Ryan, & Soenens, 2020). When applied specifically to cleaning work, autonomy would denote cleaning workers' personal values and goals driving their tasks, and them having a degree of freedom and personal responsibility in choosing their favoured approach to their work. This could include providing them with opportunities to define their own tasks and work, through processes like job crafting (cf. Demerouti, 2014). The cleaner can work independently, doing tasks that allow for freedom of choice and creativity. Related sociotechnical values include self-sustainability, ambition, and freedom.

Competence forms a part of SDT (Deci & Ryan, 2012) largely based on the motivational theory of White (1959), and can be understood to refer to a person's (perceived) ability to effectively, and 'competently,' interact with their environment, as well as their potential for improving their capabilities through development and learning. A sense of exploration and novelty can be an important contributor to feeling motivated in one's tasks and work (Vansteenkiste et al., 2020; White, 1959). According to Ryan (2009), there is a natural tendency for humans to want to learn and seek out challenges, and to be effective in their activities. For the specific context of professional cleaning work, workers' sense of competence would be based on how effectively they feel they are at fulfilling their cleaning tasks, and the degree to which they feel like they are developing new skills or doing new tasks. The first part is enhanced when the cleaners feel like they are more successful in fulfilling job demands. The second part of competence would be supported by cleaning workers regularly taking on new tasks and learning new skills they can apply in their work. Notably however, this can be challenging since cleaning work is in its current state very reliant on routines in its tasks, with workers generally needing to perform the same activities in the same manner every time they clean a location. Sociotechnical values related to competence include varied work, ambition, and growth potential.

Relatedness as a motivational factor refers to a person's sense of belonging to and being part of a community, building close and trusting relationships with other humans (Deci & Ryan, 2012). Baumeister and Leary (1995) alternatively use the term 'the need to belong,' which asserts that people require both frequent interaction with other humans, preferably consistently the same people, and for there to be a stable relationship of concern and caring in those interactions. Such relationship can include family, romance, and friendship. In a work context, there are also collegial relationships that can be formed and nurtured, and the need is better satisfied when the work allows for interdependence between colleagues and the forming of and identification with work groups (Gagné & Deci, 2005). More specifically to professional cleaning work, relatedness represents the building and maintaining of relationships internally amongst cleaning workers, as well as externally between cleaning workers and the other people in the environment they clean. Such relationships must be supported by the work structure and environment. Ashforth and Kreiner (1999) have proposed that particularly for stigmatized dirty work occupations, such as cleaning, it is of increased importance that workers are capable of building a community with their colleagues in the same occupation, as this enables a more positive

self-identity. For the topic of robotisation, it can moreover be important to consider how a robot could act as a good colleague, as explored by Nyholm and Smids (2020). Through social features, it is potentially possible for a robot to be an effective enough social agent for a human worker to build a relationship with that satisfies the need for relatedness. Sociotechnical values connected to relatedness include trust, collegiality, and solidarity.

## 3.2. Workshop methodology

To study the vision with regards to robotisation of cleaning tasks, as well as the values at stake, a workshop session was conducted with cleaning industry professionals as participants. In the session, participants first discussed the current state of cleaning work, including positive and negative aspects, and how they would like to see the nature of cleaning work and the industry change in the future. They were also asked to indicate the social values they deem most relevant for cleaning industry, and how those values could be impacted by robotisation, positively or negatively. The following section will describe the overall study design, as well as materials used, and the specific procedure that was applied.

### Workshop design

A variety of potential participants with background and experience in the professional cleaning industry was approached to take part in the workshop. Contact information of potential participants was gathered through collaboration with labour organisations. Participants included representatives for cleaning workers, labour unions, employers, and service industry consultants. In total there were ten participants, who were divided into three sub-groups to allow for more in depth discussion. Each sub-group was overseen by a facilitator who kept discussions on topic and took notes. The workshop session mainly consisted of discussions between these participants on predetermined topics. All participants were Dutch-speaking and worked in the Dutch cleaning industry, and hence the session was conducted in Dutch. As a result of the ongoing Covid-19 pandemic at the time, the session was conducted through an online conference. The overall session and collaboration between participants were supported by an online whiteboard environment where notes could be taken and tasks assigned. Voice recordings were made of the overall session and in each sub-group.

The session consisted of two parts. In the first part, each sub-group discussed the results of a homework assignment that they had completed in advance of the session, which asked them to consider the tasks, benefits, and challenges that currently characterise the cleaning industry. Following this, they discussed ideas for how cleaning robots could support those tasks, strengthen benefits, and reduce challenges. In the second part of the session, participants were tasked to consider the sociotechnical values that they deemed relevant for the cleaning industry, how those values could be impacted by the introduction and specific design characteristics of cleaning robots. The impact of robots on such values could be both positive and negative.

### Workshop materials

In advance of the session, participants were sent a homework assignment to complete in preparation. The assignment was adapted from the product value canvas (Osterwalder & Pigneur, 2010). Participants were asked to fill in the left side of the value proposition section of the canvas, describing for themselves the tasks, gains, and pains of the current cleaning industry and specifically their work within it (figure 3.2.).

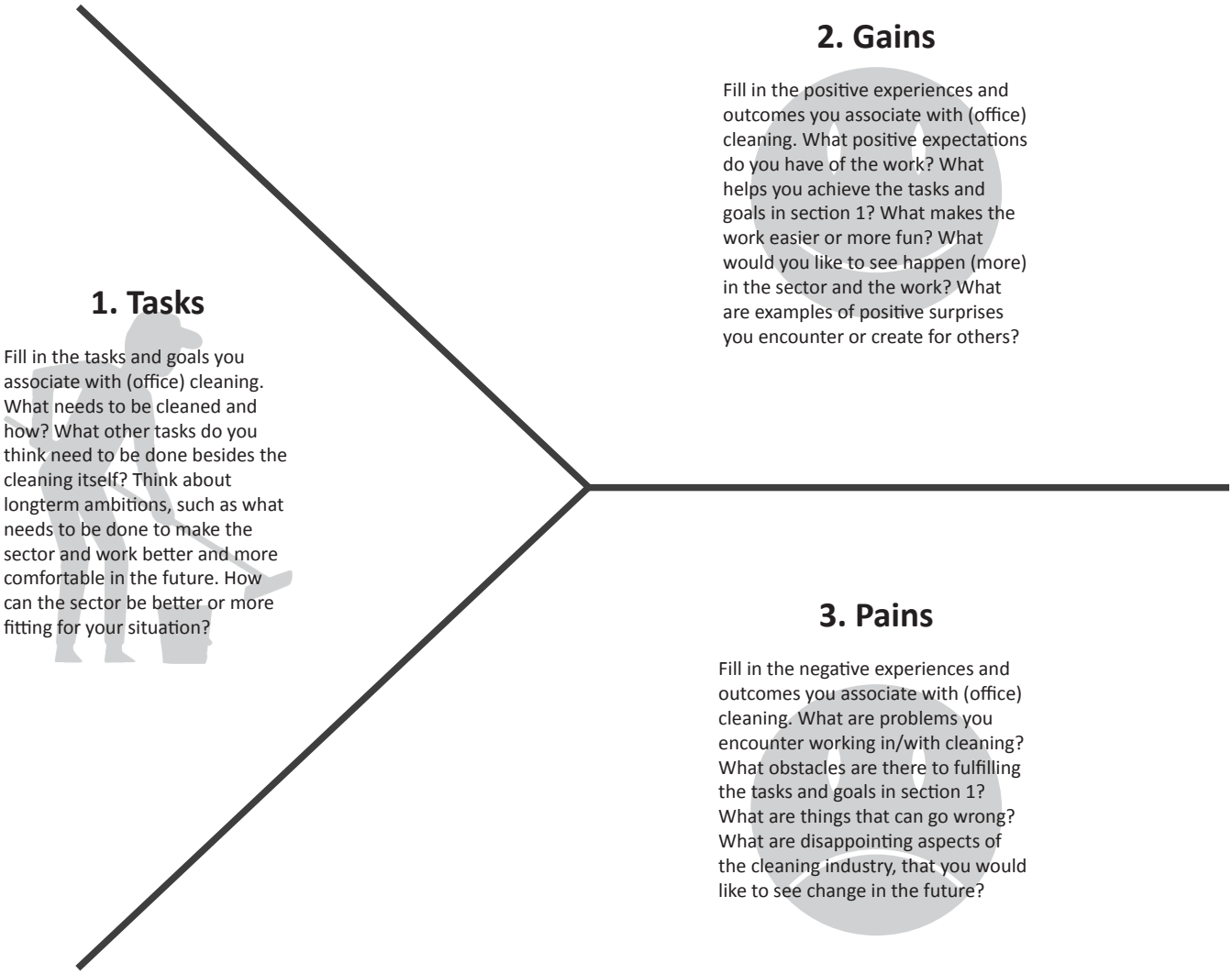


fig. 3.2. Preparation assignment value canvas

The session proper was conducted in an online Zoom conference for the purposes of communication between participants and facilitators. The shared whiteboard environment was facilitated through the online platform Mural. In advance of the session, participants were provided with instructions on the use of these services. The whiteboard area was set up to provide assigned workspace for each sub-group, and divided along the two main parts of the session, with brief instructions for each part as well as space for conclusions (figure 3.3. and 3.4.). Participants could write and place digital post-it notes to fulfil the tasks.

## Workshop procedure

The session was opened with an introduction presentation on the background of the overarching research, and the topic of robotisation in the cleaning industry. Examples were shown of current cleaning robots, and the types of topics and values that could play a role for the social impact of robotisation were introduced. Participants were given a brief overview of the session and timeplan, and were then divided into three sub-groups.

The first assignment of the session was introduced. Participants would first in their sub-groups discuss their results from the homework exercise of filling in the first half of the value proposition canvas with regards to cleaning work. That is to say, the tasks, pains, and gains they associate with current cleaning work. Next, they were to collaboratively fill in the second half of the adapted canvas, consisting of functions (representing services

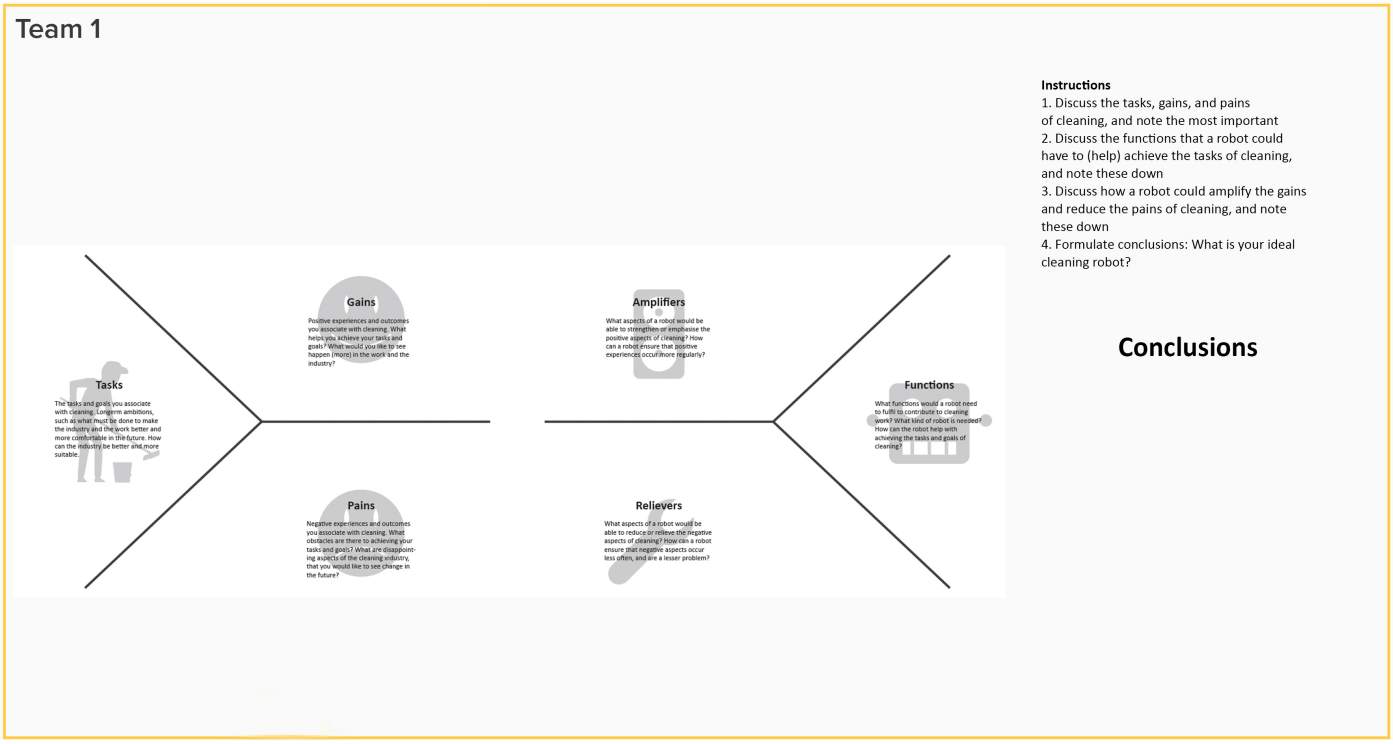


fig. 3.3. Workshop whiteboard area, part 1

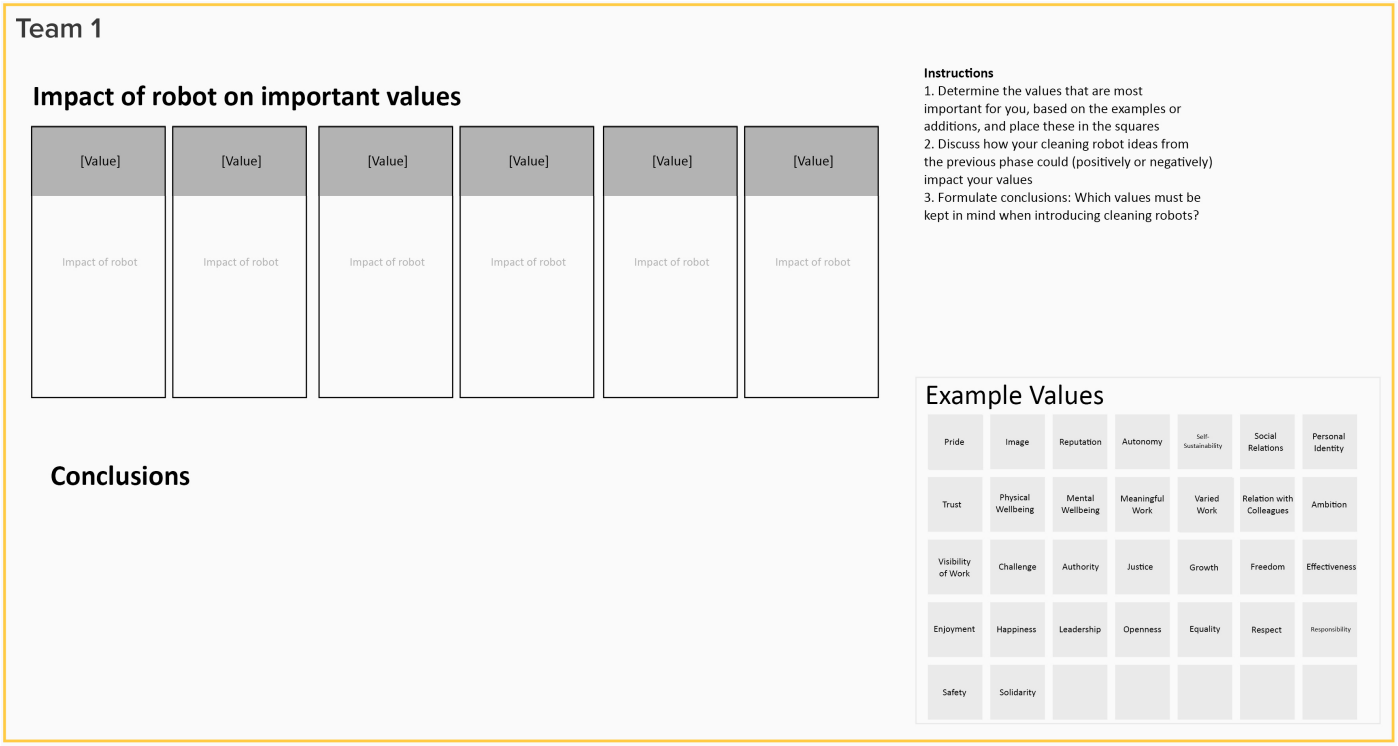


fig. 3.4. Workshop whiteboard area, part 2

and capabilities a robot could offer), gain amplifiers that strengthen benefits of cleaning work, and pain relievers that could reduce challenges (cf. Osterwalder & Pigneur, 2010). Based on this, they were asked to formulate conclusions on what their vision was for how a cleaning robot could contribute to a better cleaning industry in the future. Each group then presented their results and conclusions in the shared session, and there was time for questions and discussion.

Next, the second assignment of the workshop was introduced. The concept of sociotechnical values was explained to participants, with examples from other technologies as well as theoretical impacts of cleaning robots. On the whiteboard, participants were provided with a list of values that they could consider relevant for cleaning work, as well as space for them to add their own. The list of provided values was generated beforehand to encompass known issues and concerns within the cleaning industry, and to offer a more specific set of values compared to for example the basic values theory of Schwartz (2012). In the sub-groups, participants were asked to first indicate individually which values they deemed most important. They would then together select up to six to discuss further. They were asked to propose how a cleaning robot, as envisioned in the previous assignment, could affect the selected values. It was emphasised that such impacts could be negative, positive, or potentially both. Based on this, they were asked to formulate conclusions on which sociotechnical values should be kept in mind when introducing cleaning robots, and what the overall impact of robots could be. Each group then presented their results and conclusions in the shared session, and there was time for questions and discussion.

The workshop session was closed by reiterating the overall goals of the session, as well as summarising apparent results and conclusions. Participants were informed about how the gathered results would be used in future research on the design of responsible cleaning robots. Finally, the participants were thanked for their contributions, and given the opportunity to ask any remaining questions about the research.

## 3.3. Participants' results

In this section, the results from the workshop session will be described. The results are divided into two parts, each focussing on the respective topics explored in the workshop. Since the session was conducted in three groups of participants, each group's contributions will first be discussed separately after which general conclusions for the respective parts are summarised. The descriptions of results are directly based on the contributions of participants and the opinions and beliefs expressed therein.

### Part 1: Challenges

According to the first group of participants, the overall goal of cleaning work is to create a better living environment. The environment needs to become healthier, more pleasant, safer, and of course cleaner. In the (near) future, cleaning work needs to be made easier, more pleasant, and safer. It needs to however also be ensured that there is not less work available, so human cleaning workers can keep working. Participants appreciated that the work allows for interactions with many people, who are benefited by clean surroundings. The work is varied and being delivered at all times of the day. Participants felt like the Covid19-pandemic seems to have improved the public image of the industry, with there being more appreciation for the work. However, it is still not yet seen as having equal standing by the outside world, being looked down upon or rendered invisible. This is considered a contributing factor to clients wanting to pay as little as possible for cleaning work. The stressful and repetitive work moreover leads to a high amount of sick leave

and a burden on the healthcare system. There is a shortage of workers, and workload is considered to be very high. Additionally, cleaners have little freedom and autonomy to shape their own tasks and approach. Robots are seen as an opportunity to make the work more varied, and improving the experience of cleaning work. They can take over unsafe and stressful tasks. Operation must be intuitive and understandable, so no trained specialist is required. Robots could make use of sensors in the working environment, and the Internet-of-Things, although privacy needs to be taken into consideration for such purposes. Financially speaking, it is important that a robot can earn back its investment.

The second group of participants started by describing how cleaning work involves many physically stressful tasks that take place near the ground, which has consequences for the health of workers, reiterating points made by the first group of participants. This group emphasised therein that cleaners often need to duck to pick up rubbish from the floor. Moving vacuums and pushing cleaning carts similarly demands significant effort. In the future, cleaning work could include new tasks, such as catering. It must be considered whether (current) cleaning workers are capable of operating an advanced robot, or need additional training. It is also which tasks will remain for the human once a robot starts taking over. Human cleaners could for example take on the role of host, taking questions from other occupants and visitors to the building. This could make the work less monotonous and stressful. It could allow for 'job-carving,' that is to say allowing workers to decide for themselves what tasks to work on and how. Other users of the building may still prefer the presence of a human cleaner, who they can see and talk to. Service quality needs to be continuous and reliable. As a potential robot, there could be a cleaning cart that can move itself, or a robot that can clean toilets. It is important that a robot can move across doorsteps and over stairs. For certain tasks, a robot needs to pick up objects, for example using an arm. It needs to be thought about what the ratio between the amount of human and robot cleaners should be. If a human can operate multiple robots at once, this could enable them to work 'alone' on whole buildings at night. The question is raised to what extent a robot will be able to work independently, without the need for constant presence by a human supervising. It could be interesting to consider how robots could clean corners and hard to reach areas.

The third group of participants emphasised that cleaning is about purity and hygiene. Quality should be prioritised over speed. Cleaners have an additional function of communicating defects to clients, such as broken lights. Cleaners should be seen as a part of the organisation, and the industry as a whole could be seen and appreciated more. This would allow workers to fulfil their tasks with suitable workload, as well as develop themselves to offer better quality. They need to be able to work healthily and safely in the future, with proper working conditions and a sustainable employment. Cleaning offers access to the job market for a wide variety of people. In line with the comments made by the first participant group, the overall perception of cleaning seems to have improved as a result of Covid-19, as it has come to be seen as more important. There is however still a high workload, and the tasks often involve heavy labour. There is also not always room for growth for workers. There is potential for the use of 'cobots' that can alleviate pressure on workers. Investing in robotisation thereby has a good Social Return on Investment (SROI), as employment can be more sustainable. It needs to be an investment in the cleaners themselves. Better quality can be achieved in the same amount of time, with a reduced workload on humans. Robots can also improve the public perception of the industry because they are seen as 'cool,' and can make the work more visible. By taking over the heavy and repetitive tasks, the human cleaner is given the opportunity to focus on new fun tasks. Workload can thereby be reduced. Gaining experience working with a robot can give workers better opportunities to move into new industries. The most

important goal is that the robot must be a colleague, not a competitor. In doing so, they can contribute to democratising the industry, and improving the position of cleaners.

In summary, participants overall defined cleaning as being about the improvement of the living environment, wherein the primary goal is providing quality. There needs to be an added value for the people using the cleaned building, which allows them to work better. This can hence be interpreted as emphasising the value of quality and effectiveness in cleaning. The value of social engagement in cleaning also needs to be preserved, because that is what makes it truly enjoyable and meaningful. The human cleaner needs to remain seen, even when robots are added, strengthening the values of visibility and appreciation. This may have already happened somewhat following Covid-19, but this trend should be continued. It is also good when the tasks are varied and the industry remains accessible for everyone. Working conditions can be made healthier, with a lowered workload. Cleaners should get more freedom and independence to use their own approach, also with robots. In the future the work should be made more comfortable, but there should not be less work, preserving employment and self-sustainability of workers. Cleaning robots should take over the stressful and boring tasks, so that the work of the human becomes easier, more varied, and more fun. If possible, cleaners themselves should be able to operate the robot. This may require additional training, to enable cleaners to engage in human-robot interactions. Being given the opportunity to learn such skills would in addition enhance their pride and self-sufficiency.

## Part 2: Values

The first group of participants firstly designated safety as an important value to consider. It for example needs to be ensured that the human does not need to lift the robot, as this will likely be an unsafe task. A robot could also take over unsafe industrial tasks from the human, or measure and warn when the human is working unhealthily with regards to posture or air quality. Another important value is to maintain the work satisfaction and pleasure of the cleaners, and ideally improve those aspects through the implementation of a robot. To achieve this, labour unions and employers should be involved in the design process through co-creation. Improving work satisfaction is expected to be most effective at small clients and buildings, where the human would usually work alone and the robot can offer a degree of companionship. The third value to pursue is meaningfulness in work, as this will also impact the overall work satisfaction. A cleaning robot should take over the repetitive and less fun tasks. This allows the human to focus on more important and meaningful tasks in the building. Effectiveness and trust are also important values that are connected. Trust was here interpreted as trusting that the robot shall complete its tasks effectively and successfully. There is also a financial component to this, as the robot needs to function successfully since otherwise it will not be used and hence not be worth the financial investment from the company. If a robot is not safe, fun to work with, and effective, it will keep sitting in the cleaning closet.

The second group of participants first named physical health as important for the cleaning industry. This mainly concerns the physical health of cleaning workers. To support their health, a robot should take over the physically most stressful tasks, so the human can do lighter work. Examples are mopping floors, picking up objects from the floor, and cleaning corners and stairs. Besides physical health, mental health of cleaning workers is an important value. Cleaning robots can take over repetitive and monotonous tasks. This enables humans to take on a broader and more varied set of tasks. This should achieve better mental wellbeing in cleaning work. Combined with physical health improvements, this should reduce the need for sick leave. Employees can work more often, and have more enjoyment in their work. A third important value for some is the desire for more

appreciation and ambition within the industry. One idea is giving cleaners more prestige by allowing them to become a point of contact within the building. The role of robots therein is that robotisation allows humans more freedom to fulfil such social tasks.

In the third participant group, it was deemed important that workers have a degree of independence. When there is a good collaboration between human and robot, with the right division of tasks, this can enable more independence. Robotisation can ensure there is more time for human workers to build a better balance and freedom in their approach, with higher autonomy. It should be noted that the independence of workers is at risk of being reduced if they are 'banned' from doing particular tasks because the robot will do them. Similar to comments made by the first group, participants in this group also felt that it needs to be determined how cleaning work can be made meaningful. It is expected that cleaning will become seen as somewhat more meaningful and important if there are investments in the industry to purchase expensive robots. A new tasks division can moreover ensure there is meaningful work left for humans. On the other hand, robotisation can give the impression that humans are no longer needed, which would reduce the meaningfulness of the work. Physical health is also once more an important theme. With robotisation, the human can do less stressful tasks, and there will be fewer ergonomic problems as the robot will do heavy lifting and picking up objects from the floor. There is however also a comparison made with current vacuum cleaners, which are often problematic with regards to effort and posture, and cleaners needing to lift them across doorsteps and stairs, similar to the safety risks proposed by the first participant group. If robots exhibit similar problems, it would be detrimental for health. It also becomes a problem if there are only difficult tasks left for the human such as corners and ledges, because the robot is unable to do them. There needs to be a good balance. Visibility of the work done by cleaners is a further important value. The visible presence of robots could underscore the perception by the other users that a building is being cleaned. This would thereby also more explicitly emphasise the positive impact of cleaning and make it more visible. However, the opposite could also occur that humans think a space is less clean if they know it was done by a machine. The final value designated by this participant group was work enjoyment. Since work makes up a large part of people's lives, it is essential that they find it enjoyable. A good robot can make the work more fun, so that people look forward to going to work. A robot could be endowed with an adventurous or funny personality. Ideas are gimmicks like letting the robot talk or dance. The robot could moreover offer a social function for cleaners who work alone in small buildings, giving them a sense of safety. With regards to this, it does need to be kept in mind that after a while a robot becomes normalised, and thus the novelty and added value for enjoyable work will go down.

In summary, participants in this part designated the values they deem most relevant for cleaning work, and how those values could be impacted by robotisation. Both the physical and mental health and wellbeing of cleaners need to be accounted for. Robots can play a role in this by taking over stressful, unsafe, and repetitive tasks. This will allow humans to do easier and more varied work. This is expected to also enable more work satisfaction and enjoyment. The use of robots can ensure that cleaning work gets more visibility and thereby possibly more respect. It can give cleaners the opportunity for more social tasks. Meaningful work is left for the human, which the cleaners can focus us with more freedom and independence. The work can become more fun and enjoyable through robots.

## 3.4. Analysis of workshop results

The results of the conducted workshop have produced a set of values and topics that industry stakeholders deem of particular relevance for robotisation in professional cleaning. These results point at values and corresponding worker needs that should be considered to achieve responsible implementation of cleaning robots in practice. To integrate these results with the framework of SDT, they can be clustered to connect with one or more of SDT core needs of autonomy, competence, or relatedness. Based on this integration, it would then also become possible to evaluate whether SDT is able to provide full coverage of the themes relevant for labour robotisation in specifically the cleaning industry.

### Clustering of values in SDT

Below, the resulting themes and values from the workshop session have been clustered by association with the three basic wellbeing needs proposed by SDT. Since there is an amount of thematic overlap between the three needs, certain values are associated with more than one basic need. Moreover, certain outcomes could not be easily fit into any of the three needs, and will hence be discussed separately. A visual summary of this clustering can be found in figure 3.5.

#### Autonomy

Based on the workshop results, within the current state of professional cleaning work, there are certain risk factors that can inhibit workers' autonomy. Participants described that the work is at times repetitive, which indicates lacking autonomy. They also mentioned there is a lack of freedom in shaping their tasks and approach, whereas optimising for

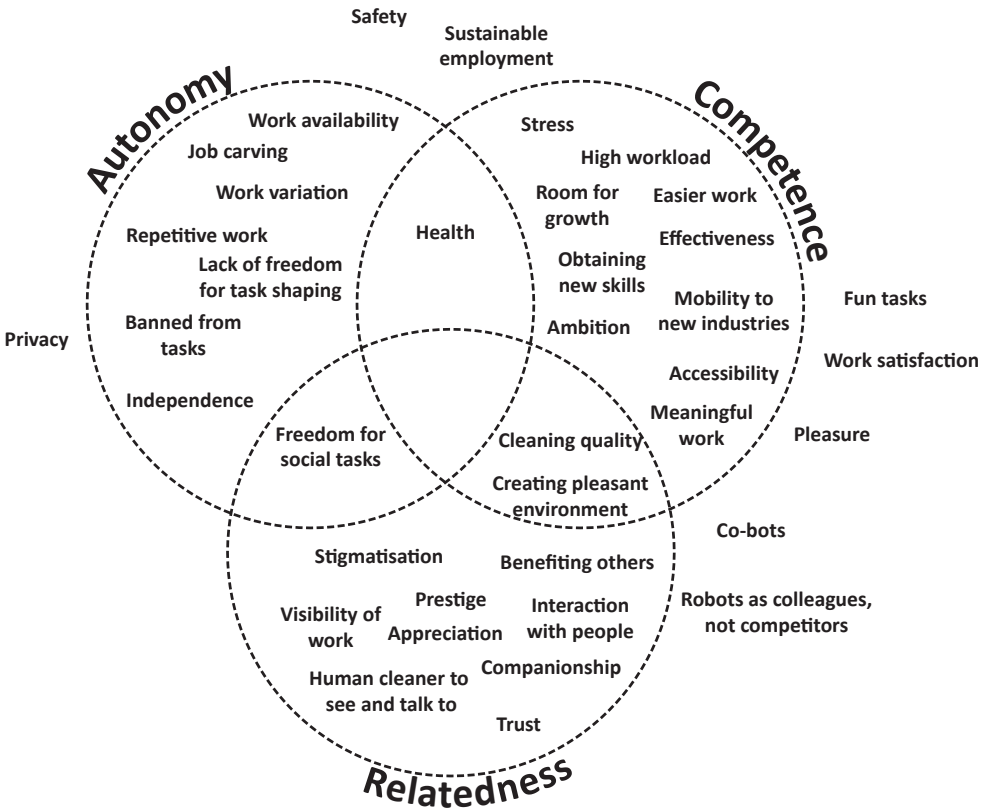


fig. 3.5. Value clustering

autonomy should ideally enable such freedom. There exists a fear that the introduction of robots could lead to cleaning workers being banned from doing certain tasks, primarily as a result of those tasks being taken over by the robot. When this happens and no replacement tasks are provided for the human, this leads to them having a more limited and monotonous work experience, and hence would inhibit their autonomy.

A first factor that can be related back to supporting autonomy is the desire for availability of work. In order for cleaners to be able to have freedom of choice and autonomy in their work, there do need to be tasks available for them to do. Moreover, there ideally then must be variation in those tasks, counteracting the risk mentioned above of workers' tasks becoming more limited due to certain activities being taken over by a robot. This would mean different types of activities being available, such as different areas to be cleaned or different types of cleaning to be done. However, such variation only supports autonomy if the cleaner has some degree of choice to make for which task they want to be doing at a particular moment. When combined with a potential freedom to add new tasks on their own, such freedom of choosing what tasks to tackle and how to tackle them could fulfil participants' call for job-carving. This should enable them to have more balance and freedom in their approach, thus fulfilling their basic need for autonomy. New tasks could include the freedom to do social tasks that have been proposed for cleaners, such as hosting duties for the building as well as social engagement with regular workers at the building. A core value that participants named during the session was independence, which also connects with the need for autonomy, as a worker's independence can facilitate the aforementioned freedom of choice and approach that is required for autonomy fulfilment.

**Competence**

A first aspect of current cleaning work that risks inhibiting workers' need for competence is the high degree of stress placed on workers, both physically and mentally. When the physical health of workers is negatively impacted, such as by a high muscle load in certain tasks, this reduces their ability to fulfil their job effectively and competently since they need to be in good health to do so. Similarly, if the mental health of cleaners is impaired, as a result of mental stress or repetitive tasks, then this also limits their ability to be competent. There is hence also a degree of overlap with the need for autonomy, since that need is as mentioned above also harmed by the repetitiveness of certain tasks. This stress is also strongly related to the high workload that workshop participants described as characterising the current cleaning industry, and it is this workload that leads to the described negative health impacts that limit competence. Participants described that there is also a lack of room for growth for cleaning workers, in that there is not much space for career mobility in the industry. This lack of room for growth can limit workers' ability to feel like they are becoming more skilled and proficient at their work and being recognized for that.

To counteract the issue mentioned above of high stress and workload, participants described that they would like robotisation to lead to easier work. They are thereby referring not to the work becoming less complex, because cleaners do desire to be challenged, but rather the work being less strenuous physically and mentally. This would enable them to work better and more healthily, and hence support their need for competence. Participants also proposed that the implementation of robots could enable cleaners to obtain new skills, for example as an operator of advanced robotics or as a building host. The learning of new skills is inherently tied to the sense of competence. This could moreover facilitate workers to gain experience to be able to move to new industries, thereby countering the above-mentioned issue of lack of room for growth that limited potential competence fulfilment. This could also fulfil the value of ambition that workshop participants described.

Conversely, participants did mention that as it stands, the cleaning industry currently is fairly accessible as offering work to demographics that may have difficulty finding employment in other industries. By giving such people an opportunity to apply their skills and work, it supports their need for competence. Participants defined that the fundamental goal of cleaning work is to create a pleasant environment for the other users of the space. It is therein essential to achieve a high quality of cleaning, which participants specifically related to them valuing effectiveness in the cleaning work. Finally, participants described that it must be ensured that workers experience their work as meaningful, for example by having their work be valued or by it being clear and perceivable how their actions lead to a cleaner environment. This value of meaningfulness of cleaners' work hence strongly relates to the need for competence.

**Relatedness**

The need for relatedness within cleaning work is currently being limited by various factors and aspects of the industry. Firstly, there is the current (in)visibility of cleaning work, where the presence and activities of cleaning workers get at times ignored by other people in the environment, with a related lack of appreciation for the work as a result. This also relates to the at times unfavourable public image of the cleaning industry, which as the participants described is often looked down upon or stigmatised. These issues of visibility and public image limit workers' ability to fulfil their need for relatedness, as it prevents them from building positive external relationships with non-cleaners in their environment.

At its core, fulfilling the need for relatedness relies on there being space for interaction with other people, as was described as desirable by participants in the workshop. This could be based on the result of benefiting others with cleaning work, by producing a better environment for other occupants, thereby not only strengthening workers' sense of competence as mentioned in the previous section, but also through appreciation received for such work strengthening their sense of relatedness. Such appreciation being given would be reliant on a change in the public perception of cleaning work, for example through a higher prestige of cleaning workers and an overall more positive culture. Workshop participants did describe that industry clients have expressed a desire for having a human cleaner to see and talk to, even as robotisation occurs. This is attributed mainly to a desire for maintaining space for social engagement, and can hence be interpreted as a desire to fulfil a need for relatedness on the part of both cleaners and the other occupants of the environment. Combined with the potential assignment of new tasks such as hosting to cleaners, this would mean giving cleaners more freedom to fulfil social tasks, which was already described previously as supporting autonomy, but also impacts relatedness. With regards to specifically a robotic colleague, workshop participants mentioned a potential sense of companionship could be achieved through the robot, as it comes to act as a form of colleague and ally to the cleaning worker. One final value that participants mentioned was the need for there to be trust in the robot. They referred specifically to needing to trust that the robot will fulfil its tasks correctly. If a cleaning robot is able to address these values of companionship and trust, it would potentially be able to provide fulfilment of the need for relatedness.

**Others**

While a considerable amount of the results in the workshop can be attributed to one or more basic needs proposed by SDT, there do remain certain findings that could not be directly related as specifications or subordinate values of these needs. Participants for example also emphasised the value of safety as being important. This can be considered connected to the health concerns that were related to the need for competence, but it also represents a more overarching desire for worker safety. This also relates to the

mentioned desire for sustainable employment, that is to say workers being able to stay in the job for longer times rather than having to quit due to health problems. Participants also mentioned that with the introduction of robotics technologies it will be important to maintain privacy of workers in the environment. Indirectly, an infringement on privacy could have an impact on workers' sense of autonomy. During the session, various concepts in regards to human-robot relations were discussed, such as co-bots, collaboration, and robots as colleagues rather than competitors. This indirectly interacts with the earlier mentioned requirement for trust and companionship that would be necessary for a robot to offer relatedness fulfilment. Finally, there was extensive discussion in the session about workers needing to have 'fun' tasks to work on, and more generally the need for work satisfaction and pleasure. These can be considered fairly general goals and values that are strived for within the industry and as part of the robotisation process. In that sense, it could not be considered subordinate to any single SDT need. Rather, it can be argued that work enjoyment and satisfaction is tied to the overall personal wellbeing that SDT's needs are intended to facilitate. Hence, it might be more accurate to say that the relation between work enjoyment and SDT is that the fulfilment of SDT's basic needs will lead to the workers finding more enjoyment in their work and feeling more satisfied with it.

## Evaluation

Having compared the results of the workshop to the theory of core wellbeing needs proposed by SDT, it can be evaluated whether it offers a suitable framework for investigating robotisation in the professional cleaning industry. Hence, what follows is an assessment of SDT's suitability for the case of cleaning robotisation, the viability of its relation to the value-oriented approach used in the study, and the implications of the workshop results for the responsible design of cleaning robots.

Based on the results, it does appear that SDT can offer a suitable core for considering motivation and wellbeing in cleaning work. As is shown by the clustering, the concerns and values of stakeholders in the industry can often be tied back to the core needs that SDT proposes. That said, the clustering also indicated that SDT as a theoretical framework may not be able to provide full coverage of all relevant topics in this specific case, as it proved difficult to directly relate back concepts such as privacy and sustainable employment. Thus, while SDT offers an effective starting point for considering work environments like professional cleaning, it will be necessary in cases such as these to take additional perspectives and theories into account as well to adapt for these themes.

In attempting to connect the value-oriented approach of the study to SDT's core of basic wellbeing needs, it was hypothesised that the values and other results could offer specification of the meaning and impact of the basic needs in the specific context of professional cleaning. A large amount of the workshop's findings did allow for specifying the meaning of the needs, as they define what autonomy, competence, and relatedness mean in the eyes of industry stakeholders. It was for example shown that stakeholders valued the personal independence of cleaning workers and that those workers should be free to choose and shape their tasks, which can be understood as giving meaning to the fulfilment of autonomy. However, the results show that the framework connection is more complex than the values and concerns being subordinate specifications of SDT needs. For example, the notion of work satisfaction was deemed as hierarchically rather above than below the basic needs. Moreover, while a concept like ambition was placed as part of the need for competence, it could also be argued that the connection would be reversed, with ambition being rather a driver for the need for competence. That is to say, workers have a desire to feel competent in their accomplishments because they are ambitious, rather than as it has now been supposed that workers would be ambitious

because they experience a need to feel competent. Hence, the interaction between the values and SDT is not hierarchical, with SDT's needs placed above the values as was proposed, but rather the concepts overlap and interrelate with each other.

Finally, it can be reflected upon what the findings from the workshop, as well as the relation to SDT, can offer as implications for the responsible design of cleaning robots to have a positive impact. Engineers developing cleaning robots should attempt to address the basic needs for wellbeing that SDT introduces. Peters et al. (2018) propose design principles that focus on these needs on a general level. The workshop results and insights can help to identify specific concerns that must be addressed as well as opportunities for cleaning robots to have a positive impact. For autonomy, it will for example be important to ensure a robot takes over the more repetitive and rigid tasks, such as floor cleaning, and leaves available to the human tasks that are open in approach and flexible, such as planning and social tasks. To support their competence, robots should also take over tasks that are stressful and physically straining, while also providing the human cleaner with a set of existing or new tasks that allow them to experience their contributions as a meaningful way of improving the quality of the environment. A concern that must also be raised is that participants highly regarded how the cleaning industry provides work opportunities for a wide array of people. It must hence be ensured that this accessibility would ideally be maintained as robotisation takes place, which in turn means that the robots must be designed to be accessible in their use and interaction. For relatedness, it would be ideal if cleaning work could achieve a higher level of respect in its public perception. Participants theorised that the industry would become seen as more important when expensive investments are made, such as the purchase of advanced innovations like robots. As mentioned, the robots could moreover be designed to offer an inherent degree of companionship and thereby relatedness for the human cleaner. A more ambitious goal would be to use the implementation of robots to support the cleaners' ability to form social relations with other humans in the environment, for example by providing them with more social tasks, or by making their presence and contributions more visible and acknowledged.

## 3.5. Discussion

This study aimed to explore the values and concerns at stake in the case of robotisation of the professional cleaning industry, and relating these to the framework of basic wellbeing needs proposed by SDT. This has indicated that though the theory of SDT offers a good core of concerns to be addressed in regards to the specific case of professional cleaning work, it does not fully cover all relevant themes and values that were discussed by stakeholders. It furthermore appears that values must be considered as more than subordinate specifications that define the meaning of the broader wellbeing needs in the case of cleaning. However, there remain limitations to the study that must be discussed, as well as opportunities for further research to support the design of responsible cleaning robots.

It must be noted that the scale of the used workshop approach is somewhat limited. The group of stakeholders gathered represents a fairly small sample size, compared to the size of the overall cleaning industry. Moreover, a large amount of the topics and concerns discussed in the workshop are most relevant and impactful for cleaning workers themselves specifically, but those cleaning workers formed only a small part of the participants group. This meant that contributions from for example employers, clients, and industry consultants was to an extent speculative about the daily work life of cleaners,

albeit based on their own industry experience. These factors limit the generalizability of the workshop results, and it is hence conceivable that further concerns, themes, and values are of interest within professional cleaning work, which must therefore be accounted for. Furthermore, the scope of the study has limited itself to the perspectives within specifically the Dutch cleaning industry, and results may therefore not apply for respective cleaning industries in other areas.

The workshop aimed to take a value-oriented approach to exploring the relevant themes in the professional cleaning industry. Participants were explicitly asked to discuss the values they deemed important within cleaning work. They were also provided with an explanation of what values are. It should be noted however that some of the results gathered would not entirely fit definitions of being values, such as those provided by Van de Poel and Royakkers (2011) and Schwartz (2012). For example, it could be argued that concepts like work repetitiveness or robot collegiality are not what would traditionally be considered values. The decision was made to focus on representing participants' own ideas and contributions as faithfully as possible, using their interpretation of what a value could be. However, this does impact the comparisons made between the frameworks of value centred design and SDT, since the evaluation brought in elements that expand the definition of values.

For cleaning robots to be successfully implemented, particularly when regarding highly autonomous robots that can act akin to colleagues to the human cleaners, it will be essential to attain a sufficient level of trust and acceptance from the humans, as was also mentioned by participants in the workshop. As mentioned, in order to achieve the needed sense of collegiality from humans towards a robot, it could try to fulfil the requirements proposed by Nyholm and Smids (2020). Engineers could furthermore make use of suitable social cues such as gaze and breathing to ease acceptance of the human-robot collaboration (Terzioğlu et al., 2020). Lyons et al. (2019) similarly propose a series of characteristics for trust in human-robot collaborations that cleaning robot developers could design for to create the needed trust that workshop participants described.

## 3.6. Conclusions

This paper has explored the potential impact of robotisation on work within the professional cleaning industry through the lens of value centred design. A workshop was conducted involving stakeholders from cleaning industry, to investigate their visions for future cleaning, the important values within cleaning, and the impact of robotisation on those values. The results of this workshop were then analysed through the lens of SDT's proposed three basic needs for wellbeing: autonomy, competence, and relatedness. Based on this analysis, it appears that though SDT can offer a suitable core for determining the needs that robotisation must support, it does not cover the full range of concerns that industry experts have raised. Moreover, it was theorised that the values and concerns derived from the workshop results could provide case-specific meaning to the more generalized needs offered by SDT. It was however found that the interaction between SDT and the results was not directly hierarchical, but rather certain values must be considered as overarching drivers for SDT's needs. Finally, it was reflected upon how engineers could design cleaning robots to align with and support the wellbeing of users, by fulfilling their needs for autonomy, competence, and relatedness.

*The preceding chapter has studied cleaning work in practice through a stakeholder workshop, to supplement and compare the theory developed previously in chapter 2 of this thesis. Moreover, the core of basic needs from SDT of autonomy, competence, and relatedness have been introduced and evaluated. The chapter has thereby through empirical research contributed to the selection of values and themes to account for when designing and implementing future cleaning robots. The theoretical and practical perspectives will be supplemented with an organisational perspective through architectural modelling, in the next chapter of this thesis. These will then be developed into a design toolbox for responsible cleaning robotisation. The values derived in this chapter, as well as the core framework of SDT, will act as a basis for the contents of this toolbox.*

# 4. Modelling of organisational transition for cleaning robotisation[2]

As became clear in previous chapters, the professional cleaning industry acts as an important facilitator of organisations, ensuring that public- and workspaces are sufficiently clean for use by others, and forms an integral component of large organisations and enterprises. Horrevorts et al. (2018) found that cleanliness of working surroundings had a significant perceived impact on the productivity and job satisfaction of office workers. Hence, the cleaning industry must be considered a primary contributor to efficient and effective work in organisations. The introduction of cleaning robots as colleagues to human cleaners raises questions about a suitable integration of resulting human-robot teams within enterprise organisations. For example, there needs to be a suitable division of tasks between human and robot, each fulfilling those tasks that are most suitable for them. Furthermore, the practical processes of cleaning will change to fit the parameters of robotic technology and collaboration between human and robot, and the impact of these changes will need to be understood and accepted by the stakeholders involved. Finally, the robotics technology will make use of sensors gathering data that must be processed. The impact of these changes on the organisational system of the cleaning industry must be analysed to achieve an effective and desirable integration of cleaning robots.

The following chapter will explore the organisational transition towards professional cleaning robotisation, and the related challenges for the design and implementation of cleaning robots in organisational practice. This will be done through a qualitative research approach, based on the lens of enterprise architecture, and the associated exchange of services between actors within the system. The goal therein is to determine organisational challenges and obstacles for cleaning robotisation, and develop a strategy of methods for overcoming those barriers. The organisational background and context of robotisation in cleaning work will first be briefly discussed. The requirements will be defined for an architecture that facilitates robotisation. A baseline architecture is modelled to represent the current state of professional cleaning industry. A target architecture will then be explored that is suggested for a new situation with high robotisation of the industry. This model and its barriers to implementation thereby offer a strategy for acceptable and effective integration of advanced cleaning robotics. These issues will need to be accounted for in the design of responsible cleaning robots, in addition to the value-based concerns discussed in previous chapters.

Enterprise architecture offers a suitable framework for studying complex organisational systems that involve multiple actors and services, such as the professional cleaning industry. It provides a means of modelling and designing these systems, as well as process developments in these systems by considering organisations as a type of product themselves and considering them through such a ‘product view’ (Bernus, Nemes, & Schmidt, 2012). Enterprises must be modelled in an integrated way to enable interoperability between domains of the organisations, and facilitate effective communication and decision making (Lankhorst, 2004). The architecture models in this chapter have been modelled based on the ArchiMate 3.1 Specification, which can be found at https://pubs.opengroup.org/architecture/archimate3-doc/

[2] This chapter was adapted from an independent research paper, written as part of the course Enterprise Architecture for EngD at the University of Twente. Raub, T. (2022) *Integration of robotics in professional cleaning industry organisations*

## 4.1. Organisational context

To understand the organisational context wherein cleaning robots must be integrated, the following section offers an exploration of the business characteristics of cleaning work and the organisational components surrounding it. There will also be a discussion of current robotisation and innovation processes within the professional cleaning industry.

### Business characteristics of cleaning industry

In a report of market trends in the European cleaning industry, the sector is predicted to have had a 100 billion euro turnover in 2016 and employed nearly 4 million workers (EFCI, 2019). As mentioned in previous chapters however, it is also dealing with a scarcity of workers and an aging workforce that drives the development of work-saving innovations (RAS, 2014). Cleaning work often consists of heavy physical labour that has had detrimental effects on the health and wellbeing of workers, including the development of shoulder and neck disorders in longtime cleaning workers (Kirov & Ramioul, 2014; Søgaard et al., 2006). Moreover, the repetitive nature of tasks such as floor cleaning can place pressure on the mental wellbeing of workers, making it more difficult for them to experience their work as meaningful and reducing their job satisfaction (Isaksen, 2000; Rothausen & Henderson, 2019). The job satisfaction and wellbeing of cleaners is moreover impacted by the way the general public perceives their work, where it is often branded as ‘dirty work’ that stigmatises and objectifies the people performing the work (Ashforth & Kreiner, 1999; Terskova & Agadullina, 2019). These wellbeing concerns, as well as the challenge of worker shortages, are main drivers for robotisation, in order to alleviate the workload and stress placed on human cleaners.

The cleaning of public and work spaces is generally outsourced to external professional cleaning companies. At times specialised consultancy organisations are involved to determine suitable cleaning partners and cleaning requirements. Organizations form service agreements with specific cleaning companies, defining tasks that must be fulfilled to achieve the desired level of cleanliness. These agreements must be financially viable for both parties. The cleaning company sends cleaning workers to fulfil the agreed upon services. Socially and organisationally, it is then not unusual for those cleaning workers to be integrated into the organisations whose buildings they clean, being assigned personal workspace and considered a colleague by employees of the organisation. With the introduction of cleaning robots, robotics developers are added into this system, who provide and often maintain the robots, and have an agreement with cleaning companies.

### Cleaning robotisation and innovation

As described in the market study in chapter 2 of this thesis, various cleaning robot products are currently on the market or being developed to address the challenges of the cleaning industry and form a part of the shift towards robotisation. A common functional focus for such robots appears to be floor cleaning, since this often involves physically straining and repetitive tasks that are relatively easy to automate. Robots took on additional interest in the context of the recent Covid-19 pandemic, which increased the societal relevance of hygiene and cleanliness to prevent the rapid spread of the virus. Robots and smart cleaning products that can autonomously map routes and spread disinfectant have been proposed as potential solutions for combatting the pandemic (Ruan, Wu, & Xu, 2021).

As the capabilities of robots advance, they can become social agents within the sociotechnical work environment, akin to cobots (Ionescu, 2020; Weiss et al., 2021). However, the stakeholder workshop in chapter 3 of this thesis indicated that the human factor of cleaning work will still need to be maintained, both due to the limitations of robots

for certain tasks, as well as clients expressing a desire to maintain the social component that is inherent to cleaning work. They wish to be able to chat with workers or have them act as hosts to visitors. As such, there will be a shift in the sociotechnical environment of the cleaning workspace, as both humans and robots will be working alongside each other. The vision for the cleaning industry is that humans and robots will be collaborating on cleaning tasks as part of human-robot teams (Groom & Nass, 2007; Hinds et al., 2004). As part of this collaboration, the human worker will be checking the performance of the robot, as well as it evaluating its own work. Based on this, future robots might also use learning algorithms to improve their cleaning behaviour to be more effective and efficient. The cleaning industry has moreover shown interest in other technologies such as the implementation of environmental connected sensors through the Internet-of-Things (IoT) (D'Agata & Di Figlia, 2020; FEP, 2019). Such sensors could for example detect when soap or paper towel dispensers must be restocked, or determine if a particular room requires cleaning based on dustiness or frequency of use. Future cleaning robots could integrate with such sensors, accessing their data, to enhance their capabilities and effectiveness for satisfactory cleaning, and thereby form designated smart cleaning solutions.

## 4.2. Architecture requirements analysis

Cleaning robots will need to be integrated into the environment of cleaning work and overarching organisational structures, demanding effective system integration. To develop a suitable system integration of cleaning robotisation, a design science approach based on systems engineering is applied (Bonnema, Veenvliet, & Broenink, 2016). The integration will need to meet requirements, which are derived from the demands of stakeholders to the system. The following section will therefore first explore the needs of system stakeholders, and following this define the requirements for the target architecture of cleaning robotisation.

### Stakeholder needs

To derive the requirements for the target architecture, it must be determined what the needs and wishes of stakeholders to the robotisation of cleaning work are. The following assessment is focussed on the main stakeholders involved, and based on the results of the theory discussed in chapter 2 of this thesis, as well as the contributions of stakeholders in the workshop described in chapter 3.

- **Cleaning workers** are the human cleaners that perform the assigned cleaning tasks, and who will in future work together with robots. They wish for easier and more comfortable working conditions, to alleviate the workload and stress that is placed on their bodies, as discussed previously. They have voiced a general vision for cleaning work to be more varied, pleasant, and fun in the future. They want job security, and for a robot to be their colleague rather than their competitor. Through the robotisation process, they wish to achieve raised efficiency with regards to the effort and workload required to clean. Cleaners need to know, based on their contracted tasks, what cleaning actions to fulfil, where, and when.

- **Cleaning company employers** are the operators of cleaning organisations that employ cleaning workers and assign them to specific clients based on agreements with those clients. They want to be able to make new and profitable agreements with clients of cleaning work. This will allow them to grow their business further, to increase profits and enable new investments. They want to send the right combination of human cleaning worker and equipment, including robots, to the right job, which they decide upon based

on characteristics of the cleaning agreement with a particular client. This must lead to improved effectiveness with regards to sufficient cleanliness. They wish to achieve raised efficiency, particularly with regards to financial costs. Notably, this is a different measure from the workload efficiency desired by cleaning workers.

- **Clients** represent organisations that are in need of having their spaces professionally cleaned, and therefore make agreements with cleaning companies to receive services. They want their spaces to achieve a sufficient level of cleanliness, with no perceivable 'dirt' remaining. They wish to be informed of the services that are provided. The clients have largely indicated that with regards to robotisation, they would prefer there still is a human cleaner present on-site. This is among others for social reasons, since the cleaners are sometimes seen as a part of the organisation. Similar to the cleaning companies, the clients want there to be efficiency in the cleaning services, specifically in regards to financial costs.

- **Robot manufacturers** develop cleaning robots, and put these onto the market to be invested in by cleaning companies, at times in combination with maintenance services from the manufacturer. The manufacturers want to sell their product to cleaning organisations, mainly by showing their robots to be a viable solution to the faced challenges. To do so, their robots must allow for a more effective and efficient cleaning process, both in regards to workload reduction and financial costs. For their robots to function, they need to know the characteristics of the tasks that must be fulfilled, and the environment. Specifically, a robot needs to be programmed with data about the cleaning location, to allow it to navigate, and it requires instructions for tasks that it must fulfil. This data would come from both clients and cleaning companies.

## System requirements

Based on the stakeholder needs discussed above, requirements can be defined that the targeted system of robotisation in cleaning must meet. It must overall integrate with the current process and agreements made between clients and cleaning companies. A sufficient level of cleanliness must be reached through the collaboration between the human and robot cleaner. The system must achieve more comfortable working conditions, with a reduced workload placed on human cleaning workers. Furthermore, it would be desirable for overall financial costs of cleaning to be reduced, to give incentive to clients and cleaning companies to invest in the technology. The manufacturers must be provided with data and specifications from clients and cleaning companies to program into the robots so they can fulfil their tasks.

This vision for the target architecture is visualised below through a motivation view (figure 4.1.). These types of models are used within the framework of enterprise architecture to illustrate and define the relations between stakeholder needs and system requirements and specifications. Successful implementation and functioning of cleaning robotisation will be reliant on the following courses of action:

- *Implement suitable user interaction:* To allow for effective operation of the robots by humans, and to support an efficient collaboration within the human-robot team, there need to be suitable interaction features. This will mainly consist of an intuitive user interface, by which the human cleaners can assign tasks to the robots, and the robots' communication features, such as audible and visual signals, which the robots can use to convey information to the operator.

- *Divide tasks between human and robot:* As the robots are being developed, it will need to be decided which cleaning tasks specifically will be automated, and which will

be left to the human workers. In this way, tasks are divided within the human-robot team. These decisions should be based on an inventory of the required tasks to achieve the cleaning goals, as well as data about for example the workload on humans of individual tasks. Cleaning workers should be enabled to offer their expertise for which tasks are suitable and desirable for assigning to robots.

- *Incorporate data about working environment:* The working environment that an individual robot will be operating in at a client's space will have certain characteristics, such as floorplans. In order to work effectively and efficiently, a robot will need access to this data, so that it can for example navigate the space as well as focus its cleaning on high-traffic areas. If technological principles like IoT were implemented in the environment using sensors, this could provide a robot with data about the current situations, allowing it to adjust its behaviour as necessary.

- *Implement robot learning algorithm:* The developed cleaning robots need to be able to evaluate their own performance, using data they gather during the cleaning process. Examples of data gathered include speed of task completion and frequency that specific areas in the environment have needed to be cleaned on previous workdays. Based on this data and its evaluation, the robot should adjust its behaviour during future tasks. To achieve this, the robots make use of learning algorithms that must be developed as part of the robots' design process.

- *Implement cleaning features:* To fulfil its assigned tasks, a cleaning robot needs to have the required features to engage in cleaning activities. It is likely that only certain cleaning tasks will be viable for automation, which will need to be identified. It is for examples currently common for robots to focus on floor cleaning tasks, as these are often monotonous. Once it is determined which tasks to integrate into a robot, the required features to fulfil those tasks must be developed and implemented.

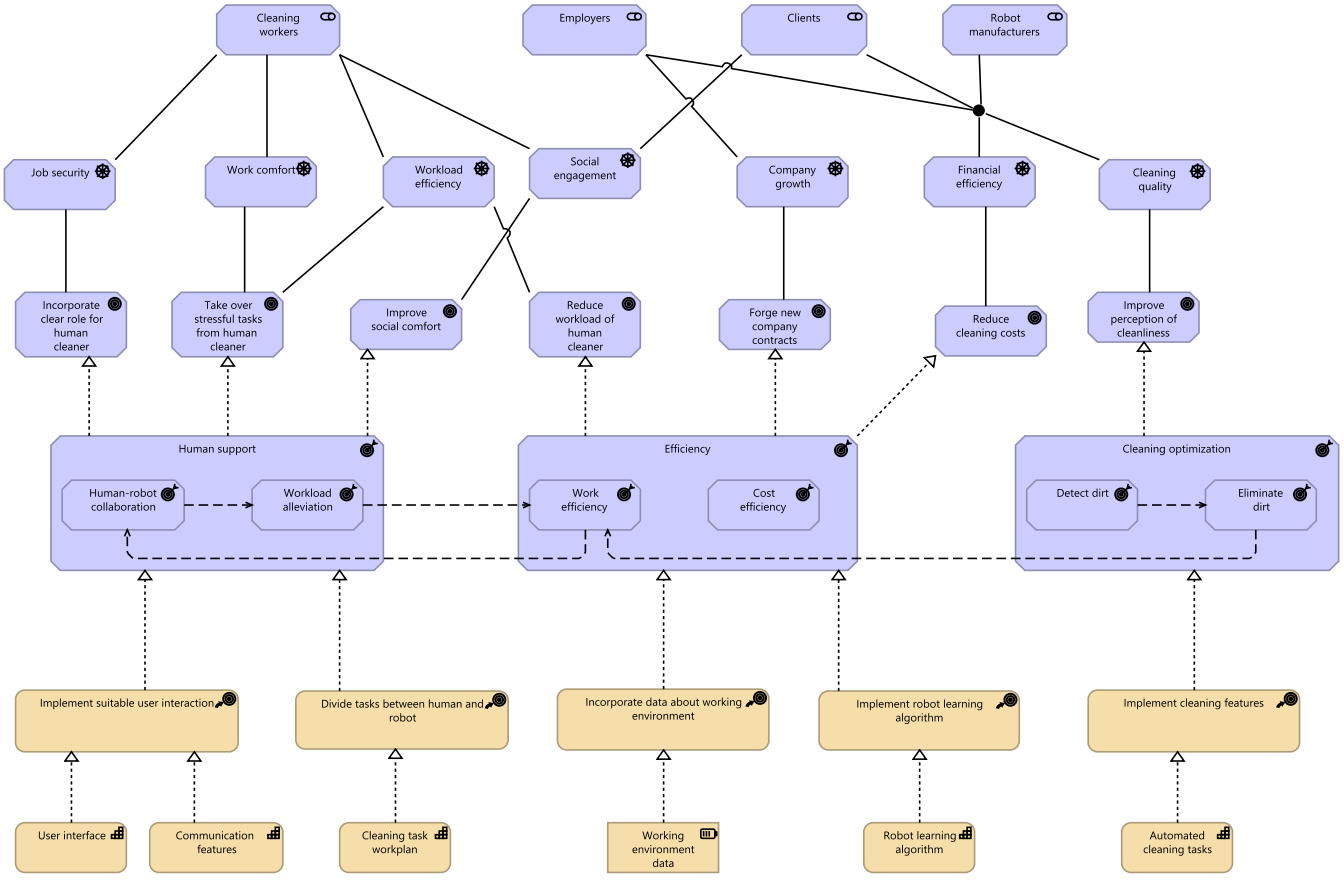


fig. 4.1. Motivation view

## 4.3. System design

The previous section has defined the driving motivations and requirements for a system architecture of cleaning work that includes robotisation. Based on these system requirements, a future architecture and transition pathway towards this architecture can be designed. To this end, the following section will first develop and present a baseline architecture of the current cleaning industry. This architecture focusses on the collaboration between an individual client organisation and a cleaning company offering services.

Based on the enterprise architecture framework, the model will consist of three layers. In the business layer, the involved business partner and actors are described, as well as their roles and tasks within the system. At the bottom of the model is the technology layer, which represents the technological artefacts and (data) processes of the system. The application layer is placed between the business and technology layers, and thereby acts as the intermediary between these layers, consisting of the interfaces used by business actors to access and use the modelled technologies.

After modelling the baseline architecture, a target architecture is proposed that incorporates the needs and characteristics of cleaning robots being implemented into the practice of cleaning work. Finally, a general transition strategy is offered for how the envisioned target architecture can be achieved, and what are potential obstacles and opportunities.

### Baseline architecture

Cleaning organisations make agreements with clients to form contracts for cleaning services to be offered, with specifications made for costs and exact cleaning activities that will be performed. The organisations then assign a suitable cleaning worker to the contract to perform the defined tasks on location at the client based on the formed assignment. The employee is thereby assigned the role of assigned cleaner for the specific contract. This cleaning worker is informed of their assigned tasks, and on a day-to-day basis defines a plan for how they will fulfil those tasks. They execute on this plan by performing the more specific cleaning activities, such as vacuuming, scrubbing floors, and cleaning furniture. The employing cleaning organisation will give the cleaner feedback on their performance, and if needed give instructions for how the work should be done differently. Similarly, the client may have requests, such as additional tasks the cleaner could perform, or for certain areas to be cleaned in a different manner. These will often be informal processes, through discussion between employer, client, and cleaning worker. The feedback and requests will be relayed to the cleaning worker, who will based on this decide how to adjust their cleaning approach from thereon. The specifications of the specific contract and assignment are monitored and managed through the cleaning organisation's contract management system. Data for this system is stored internally on the organisation's servers, and retrieved when required for management of the employment and assignment. The model of this baseline architecture of the cleaning organisations' current system is summarised in figure 4.2.

As can be seen, on an application and technological level, the system of the professional cleaning industry can be considered somewhat limited. Though the industry has generally shown interest in adopting new innovations including data telecommunication, IoT, and robotisation (FEP, 2019), these interests are largely expressed through small-scale and limited-time pilot projects, and most of these innovations are still undergoing a long process of full adoption or may never be adopted fully. Similar processes can be observed for the implementation of automated disinfection solutions described earlier (Ruan et al., 2021). This could be ascribed to a degree of hesitation on the part of cleaning organisations to fully invest in new technologies. The integration of full cleaning robots would hence represent a fairly large step of innovation for the industry.

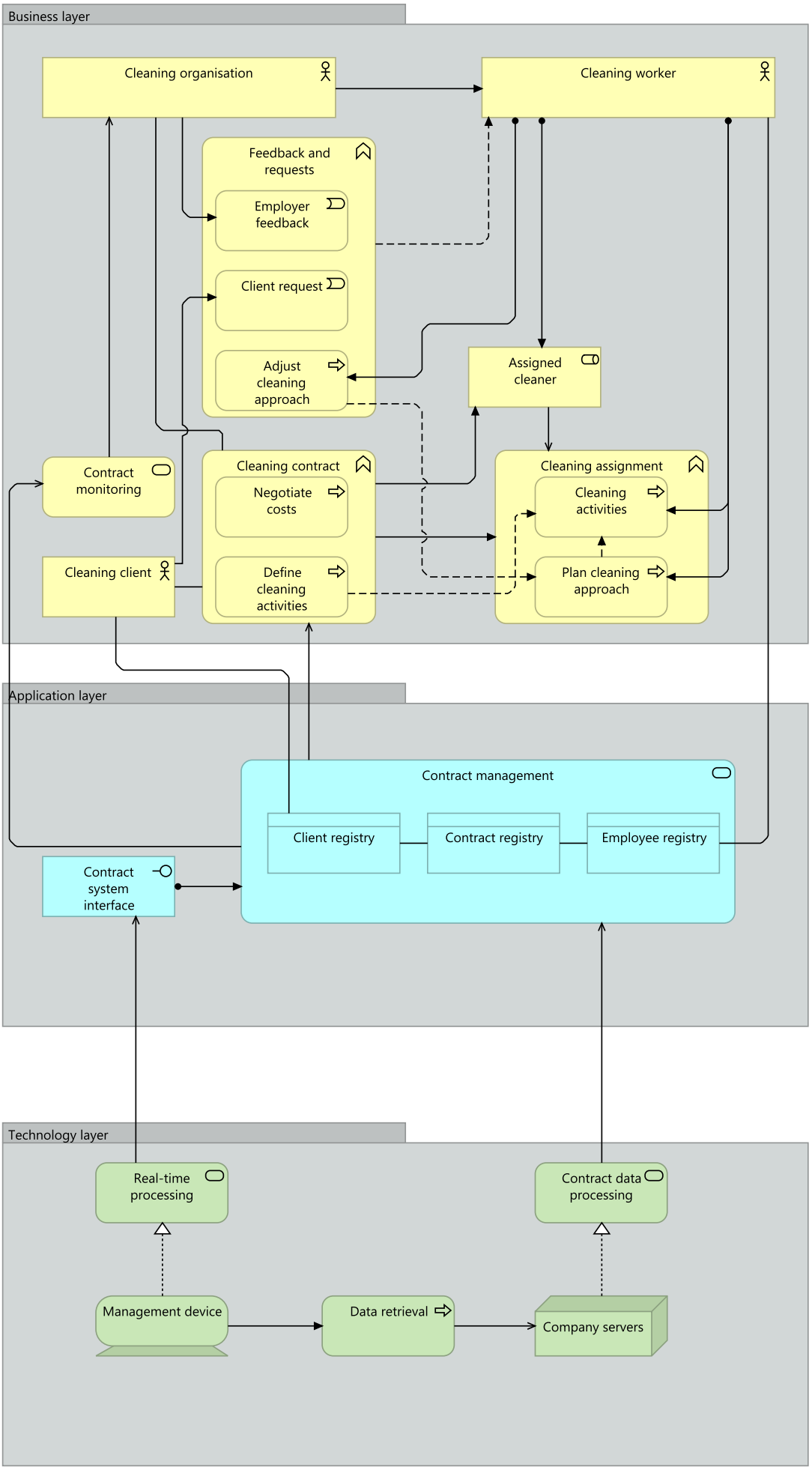


fig. 4.2. Baseline architecture for cleaning robotisation

## Target architecture

The cleaning industry is investigating a shift towards robotisation of certain cleaning tasks, which introduces a new level of technology and human-robot collaboration to the system. Agreeing on whether a robot will be used as part of the cleaning services becomes part of the cleaning contract negotiations between cleaning organisations and clients. Cleaning tasks will be as part of the assignment divided between the human cleaner and the robot, as the human assigns tasks for the robot to do based on its capabilities. This will be done as part of the cleaner's process of deciding a suitable cleaning approach, and through use of the robot's user interface. When the cleaner receives feedback and requests from their employer and client, they will also integrate these into their instructions for the robot so that its behaviour is adjusted as needed. On the application level, the robot will be monitored and managed by the human cleaner through its user interface, and it will also offer reporting on its own performance so that adjustments can be made to the system where needed. The use of the robot will also be integrated into the contract management system to allow for interoperability. On the technology level, the robot will be using its various subsystems to fulfil the required cleaning functions, and monitor its own performance to enable the reporting towards human cleaners and management. Within the working environment, sensors will be placed that are connected through IoT, reporting on aspects like level of dirtiness in particular areas, how often those areas are used, and whether resources like soap and paper towels need to be replaced. Data from these sensors will also be communicated to human cleaners and management through respectively the robot management and contract management systems, to improve the cleaning services rendered for the client. The robot performance reporting, as well as the data provided by and retrieved from the clients and environmental sensors, will feed back into a learning algorithm that allows the robot to automatically improve upon its own performance. This envisioned target architecture is summarised in figure 4.3.

## Transition strategy

Having explored the broad vision for integration of cleaning robots into the organisational system, it must now be determined how a transition can be achieved towards the target architecture from the present system. As mentioned, the baseline system of professional cleaning as it currently exists has been reluctant towards full adoption of high-tech innovations, and hence does not incorporate many advanced technologies and applications. The implementation of robotics would thus represent a fairly significant step on a technological level. On the other hand, this also means that there is less complex incumbent architecture that the envisioned robotisation will need to integrate with.

As part of the shift of integrating the robot into the work environment, the clients of the cleaning services will need to agree to a robot being used as part of service fulfilment. Similarly, the environmental sensors will need to be placed, which can raise concerns about data ownership and privacy (cf. Chatzimichali, Harrison, & Chrysostomou, 2021; Janeček, 2018; Saarikko, Westergren, & Blomquist, 2017). Alternatively, it could be the clients that suggest the use of a robot in the first place, as a means of investing in new innovations or to make the cleaning services more effective. Similarly, the human cleaning worker will need to accept the use of the robot, as well as obtain the required skills and training to operate the robot successfully (cf. Scassellati & Tsui, 2016; Schofield, 1999). As the robots as proposed will be using advanced artificial intelligence such as learning algorithms, trust will also be contingent on cleaners understanding the technology, necessitating an approach based on Explainable Artificial Intelligence (XAI) (Gunning et al., 2019; Langer et al., 2021).

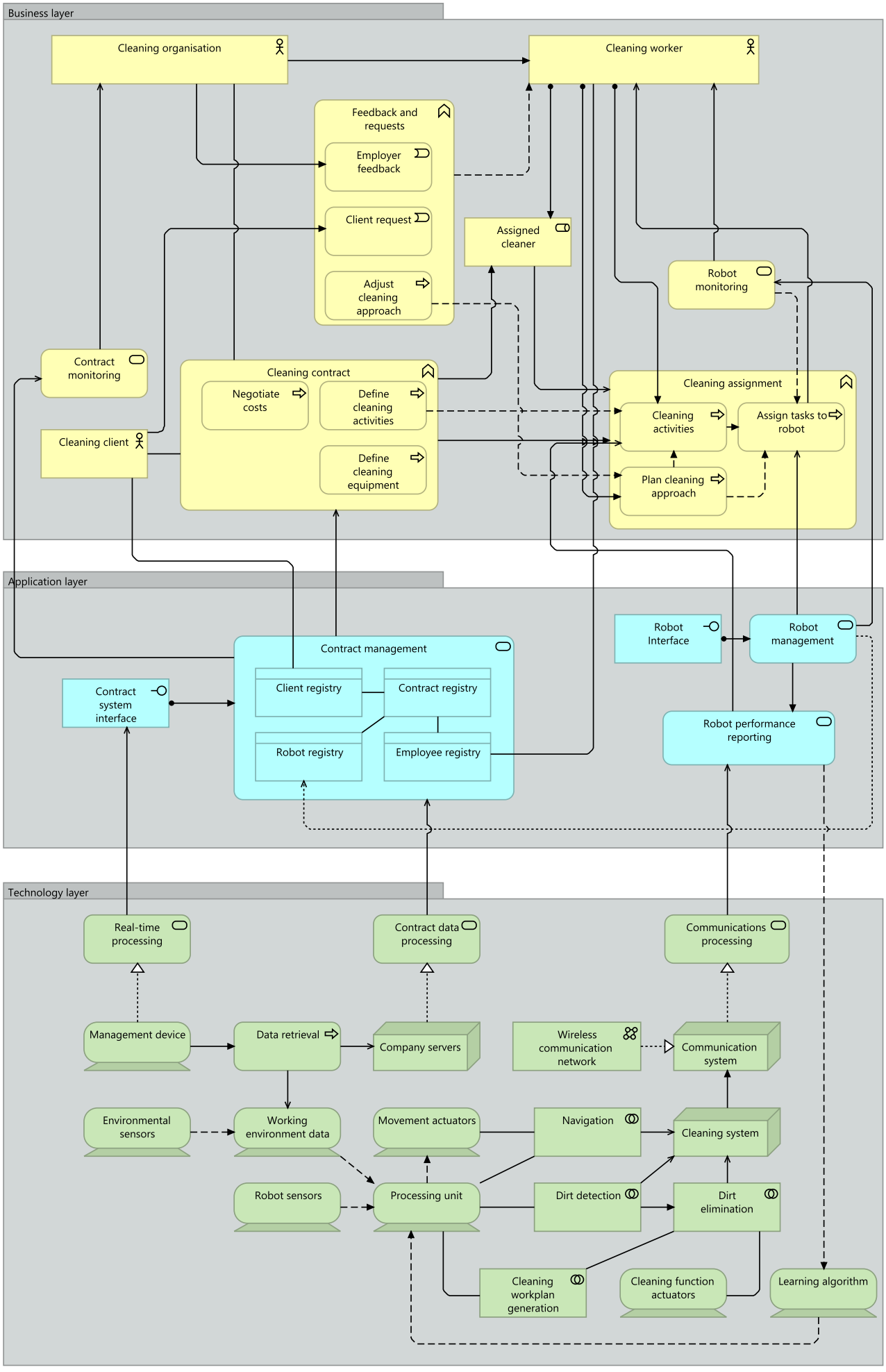


fig. 4.3. Target architecture for cleaning robotisation

Someone will need to be put in charge of dividing the cleaning tasks between the human and the robot. The human cleaners would likely be most suitable for this, since they possess the practical experience to determine an effective and efficient workplan. Their involvement should be implemented through a robot design approach based on co-design and participatory design (Buur & Matthews, 2008; Greenbaum, 2017; Sanders & Simons, 2009; Sanders & Stappers, 2008; Trischler, Pervan, Kelly, & Scott, 2018). This could moreover provide them with a sense of empowerment and autonomy, and ensure a positive impact on their wellbeing which could lead to them more easily accepting the new technology (Van Rijn & Stappers, 2008; Venkatesh, Thong, & Xu, 2012; Vink, Wetter-Edman, Edvardsson, & Tronvoll, 2016).

The human cleaners will also be in charge of robot management, through the robot interface, which must be designed to be user-friendly and accessible for them. They will need to be trained on how to give the robot instructions for fulfilling its tasks. Through the interface, they will need to receive the technical performance reporting of the robot, as well as information from environmental sensors at the client location. This reporting must be in an understandable format for the cleaning workers, giving them a comprehensive overview of the robot's activities, so that they can change instructions and intervene if necessary.

On the technological level, internal to the robot, the various functions of the cleaning system must be effectively integrated with one another. The key component to this will be the processing unit of the robot, which must handle the input from the various sensors to decide on moment-to-moment actions. The learning algorithm of the robot will be an important factor for this, to allow the robot to improve on its own behaviour semi-autonomously, with guidance from the human cleaner operator's instructions. Hence, the processing unit and learning algorithm will require considerable attention during the development process of the robot. With regards to system integration, the robot will need to be able to access the data about the working environment at the client location. This data will need to be accessed from the client company servers and sensors, and hence the robot will need to be able to connect to and communicate with these wirelessly.

## 4.4. Discussion

The target architecture proposed in figure 4.3 should provide a suitable starting point for integration of advancing cleaning robotics within the systems and organisations of professional cleaning work. The human cleaner will act as an operator for the robot, as well as a mediator that implements the feedback and requests from cleaning organisations and clients into the activities of the human-robot cleaning team. The access to data on the client's working environment through sensors and the client's company servers should enable a cleaning robot to fulfil its services effectively and efficiently. The robot's services are further progressively improved through the suggested implementation of a self-learning algorithm.

As mentioned, one of the limitations and obstacles in the robotisation process is the overall low adoption rate of technological innovations within the professional cleaning industry. This could pose a challenge to the cleaning robots and the proposed organisational architecture being accepted by the primary stakeholders that are required for investment and adoption. The benefits, including both financial and social, need to be clear for organisations to incentivise them to invest resources in the development and implementation of the robots. Human cleaning workers need to similarly be willing to work with the robots, and learn how to operate them.

The requirements for acceptance, such as profit, worker wellbeing, and work satisfaction can be understood as closely held values for the respective stakeholders, which an innovation such as robotics must preserve and address (cf. Van de Poel & Royakkers, 2011). This role of stakeholder values reiterates the need to consider the topic of future cleaning robotisation through the framework of value-sensitive design (VSD), as a means of addressing those values in a responsible manner (Friedman & Hendry, 2019). It has been suggested that a design approach for future cleaning robots based on co-design and participatory design could aid in the adoption and acceptance process. This would require robot designers to actively involve stakeholders and their concerns and needs in their design process. In doing so, they can reveal what values are at stake in the case of cleaning robotisation, and how design decisions will impact those values (cf. Manders-Huits, 2011; Smits, Bredie, van Goor, & Verbeek, 2019).

The adoption process could furthermore be supported by initial smaller scale implementations for specific clients or specific cleaning tasks and areas. This would allow for growth in such niches until the current organisational systems can be replaced, through a multi-level perspective approach for the sociotechnical system of professional cleaning (Geels, 2005, 2019; Geels & Schot, 2007).

Within the present research, the stakeholders have been somewhat simplified, focussing on the cleaning companies, their employees, and their clients. There are however as mentioned often additional intermediaries, such as facility managers, and service consultants, that for example specialise in determining required cleaning services or flexibly negotiate service agreements. These have been left out of scope of the present architecture, but can have an impact on the integration into the enterprise. Moreover, the presented architectures replicate a working environment with a single cleaning worker who is assigned to the client location and placed in charge of the robot. However, with particularly large client organisations, it is common for there to be multiple cleaning workers assigned to form a team. Within that team, it could be that there is one specific employee who will specialise in the robot operation, or the team collectively supervises and controls the robot. Similarly, there could be multiple robots implemented into the same environment. The aim should be for different robots to be operated through the same management platform, which will require standards and interoperability between manufacturers and designers in the field of cleaning robots.

Finally, it should be noted that the specific implementations and pathways for cleaning robotics are still fairly open, with regards to for example the types of cleaning features that are incorporated. In the proposed architecture, it is accounted for that the robotisation could occur in combination with implementations of environmental IoT. However, not all implementations of cleaning robotics necessarily need to make use of IoT or other environmental sensors. Specific implementations and strategies will likely need to be defined on a case-by-case basis in negotiation between cleaning organisations and clients, and be dependent on particular characteristics of clients' workspaces and the wishes and needs of the involved stakeholders. Hence, this limits the viability of attempting to offer a one-size-fits-all solution for cleaning robot implementation. That said, the target architecture proposed in this research can act as a template for specific implementations of clearly defined robotics concepts to be developed.

## 4.5. Conclusions

This chapter has explored the shift towards robotisation of human labour tasks within the professional cleaning industry, to address the current challenges of the industry including employee health concerns and labour shortages. Through the framework of enterprise

architecture, the research explored organisational challenges and obstacles for cleaning robotisation, and suggested methods for overcoming those barriers. The context and primary stakeholders involved in the organisational system of professional cleaning have been investigated to define a baseline architecture that models the current state of cleaning work. A broad target architecture has been proposed for implementing cleaning robots into this incumbent system, through integration with environmental sensors and data that allows the technology to effectively fulfil its tasks and work together with human cleaners to deliver the agreed upon cleaning services to satisfaction.

The user interface through which the human cleaner can operate and supervise the robot's performance will need to be designed to be user friendly and accessible. Additionally, the artificial intelligence underlying the robot will need to be understandable for the cleaners using the technology. The processing unit and learning algorithm that is embedded in the robot will similarly require much attention in the design process, as these will enable the robot to function effectively and efficiently and thereby enhance the collective cleaning performance of the human-robot cleaning team.

To be able to transition towards the proposed architecture system, there will need to be acceptance from cleaning organisations, clients, and human cleaning workers to use the robot, as well as there being willingness to invest, which may require financial or otherwise beneficial incentives. This must be achieved through a value-based and participatory design approach, that directly incorporates the needs and wishes of stakeholders, and involves them in the robot development process. The following chapter in this thesis will hence describe the development of a design toolbox for responsible cleaning robotisation, through the use of participatory and value-based workshop materials.

# 5. Design toolbox for responsible cleaning robotisation

The previous chapters of this thesis have indicated the need for a value-centred and collaborative approach to the design of future robots for professional cleaning, as well as introduced a range of topics and values that must be accounted for in the robots' design and implementation. Current cleaning robot design practices have not fully accounted for the needs and values of all involved stakeholders, particularly those of the cleaning workers. To integrate this knowledge in the robot design process, it will be necessary to consider value-centred design approaches, as well as methods of participatory co-creation that enable stakeholders to be part of the design process and integrate their values in the final results. Such value-centred and participatory design approaches will require guidelines and materials, to be able to engage in a collaborative development approach between designers and cleaning industry stakeholders.

To this end, the following chapter will describe the development and contents of a toolbox of activities and materials for use in participatory design workshops and as design inspiration, specifically designed for the case of robotisation within the cleaning industry. This chapter will start with a review of value-based design principles, and existing approaches for collaborative design and co-design, which form the basis of the designed workshop materials. Next, the specific contents of the toolbox will be described and discussed. In sum, this chapter will thus present the first draft for the design toolbox that is the final result of this overall research project, and which will be evaluated with designers and cleaning industry stakeholders in the next chapter of this thesis.

## 5.1. Value-based design principles

Engineering and design are inherently moral practices, that must be driven by people that are sensitive to the ethical impacts of the products they create (Roeser, 2012). Engineers thereby have a moral obligation to include ethical considerations in their design process, and to consider the impact of their work on people, the environment, and society overall. Through the activities they mediate and facilitate, products and technologies can have a lasting positive or negative effect on the long-term wellbeing of humans (Wiese, Pohlmeyer, & Hekkert, 2019). There is thus a call for people to design with emotional sensitivity, and with regard for the values that are at stake. To achieve this, they will need to adopt a user-centred perspective, driven by empathy for and understanding of the needs of end-users.

As discussed earlier in this thesis, value-sensitive design (VSD) offers a possible theoretical framework for addressing the moral concerns and impacts of new technologies, and for enabling these considerations to be included in the design process (Friedman & Hendry, 2019). VSD is defined by Friedman et al. (2002, p. 2) as "a theoretically grounded approach to the design of technology that accounts for human values in a principled and comprehensive manner throughout the design process." 'Values' represent broadly those things that a person or group of people find important in life. Van de Poel and Royakkers (2011, p. 72) define values as: "Lasting convictions or matters that people feel should be strived for in general and not just for themselves to be able to lead a good life or to realize a just society." Examples include freedom, satisfaction, and physical wellbeing. The goal of VSD then is to design future products in such a way that the values most relevant for involved stakeholders are preserved or ideally improved. It is therein worth remembering that different stakeholders can have different interpretations of certain values, and they

may ascribe different levels of importance to individual values. It moreover needs to be accounted for that values can conflict with each other, such as improvements in values of safety at times requiring reductions in values of personal privacy. VSD must acknowledge and navigate these conflicts, to for example seek a suitable balance of values or find solutions that remove the conflict.

There have been various methodologies developed to practically integrate VSD into the technological engineering process, to allow for more value-conscious products to be developed. Manders-Huits (2011) addresses the question of how to incorporate values into the product design process, by means of VSD. The core VSD methodology consists of an iterative process of three investigations (cf. Smits et al., 2019). The first step is conceptual, identifying the central values at stake in the design context, and the direct and indirect stakeholders that are affected. The second step is empirical, determining how stakeholders experience the technology with regard to the values they deem important, and how they handle value conflicts. The third step is technical, studying the design and performance of the technology, and the possibilities it creates for new behaviours. Manders-Huits (2011) does however point out that it can be challenging to account for all stakeholders, and that stakeholders may have difficulty assessing the true impact of technologies on their values. There can moreover be disagreement about interpretations of particular values, since they are often abstract and vaguely defined, and dependent on context.

These apparent shortcomings are shared by Smits et al. (2019), who also emphasise that VSD can fall short in its understanding of values by assuming that values remain stable throughout the use of a technology. In practice, they can be dynamic and change as part of the interaction between users and technologies, through a process of mediation (Kudina, 2019; Verbeek, 2015). Smits et al. (2019) hence propose an alternative approach of 'Values that Matter' that focusses on the context-dependence of values, through four design phases. First, the design problem is explored with the focus on actors and values, and mapping the values in accordance to which actors deem them important, with the goal of creating a value hierarchy. As an example, within the present research, this phase was previously addressed through the workshop described in chapter 3 of this thesis, which studied the needs and values of cleaning industry stakeholders. In the second step in the approach of Smits et al. (2019), a potential design solution is conceptualised through ideation, and iteratively further developed through future phases to develop a concept that solves the set problem while incorporating the main values. Third, technology assessment is used to anticipate the concept's effect on value dynamics, by redefining or mediating particular values. Fourth, the anticipated effects are tested through the designed concept, to determine the effect on different actors and users.

The DesignLab of the University of Twente developed its own approach for 'Responsible Futuring,' which incorporates elements of design thinking and participatory design with stakeholders to explore their vision, expectations, and wishes for future technologies. Responsible Futuring addresses societal challenges and aims to ensure a positive impact for technology on society, through responsible co-shaping of the future with societal stakeholders in a cross-disciplinary generative and reflective process (Zaga, 2021). It thereby offers a practical application of VSD, that addresses the overarching frameworks challenges by giving stakeholders the opportunity to explore a technology's impact for them, and to discuss amongst themselves what a particular value means for them within the given context. The approach builds on theory of transdisciplinarity and societal involvement, responsible design, and design thinking. There are methods and activities suggested to apply as part of the approach to effectively gather data and generate ideas from stakeholder involvement. Examples include the use of roleplaying, scenarios, design

probes, value dialogues, and collaborative lo-fi prototyping. The vision and suggestions offered by the Responsible Futuring approach act as inspiration and foundation for the design toolbox for responsible cleaning robotisation developed through the present research project, and described in the following section.

## 5.2. Toolbox components

To facilitate the responsible design of cleaning robotisation through a value-centred and participatory approach, there is a need for concrete methods and materials that help robot designers to generate suitable concepts and enable industry stakeholders to express their perspectives and needs. This would enable applying the overarching VSD framework and Responsible Futuring approach to the specific case of cleaning robotisation. These concrete methods and materials collectively form a toolbox for value-centred participatory design in cleaning industry. The following section will hence describe the development of this toolbox. The theory underlying the methods will be discussed, and the materials that have been created for the specific context of cleaning work robotisation will be presented. The materials will be discussed in the suggested order for a participatory design workshop with robot designers and cleaning industry stakeholders.

### CUTA

Collaborative Users' Task Analysis (CUTA) is a collaborative card-based technique for participatory design with technologies' end-users, invented by Lafrenière (1996), as an extension on the Collaborative Analysis of Requirements and Design (CARD) technique (Muller, 2001; Tudor, Muller, Dayton, & Root, 1993). Originally developed for the study and improvement of user interfaces, it provides a means for task analysis to allow designers to understand the actual work process of users. The technique uses cards with visual and textual descriptions of specific activities or tasks that a user may perform, with space for details about for example duration and frequency. The cards should be created for the specific context and workplace that is being studied. Blank cards are also provided to allow for the addition of unforeseen actions thought up by participants in the activity. Using the cards, users describe their workflow by placing the activity cards in order. As they do so, they can verbally describe their activities as well. This activity thereby provides both participants and designers with an overview of tasks that are involved in the work, and facilitates a discussion about those tasks.

The cards created for the toolbox for responsible cleaning robotics design have been based on training and scheduling materials used at Dutch professional cleaning organisations. The cards include the following activities:

- Cleaning furniture
- Emptying trash bins
- Vacuuming floors
- Mopping floors
- Cleaning touch surfaces
- Cleaning hard-to-reach areas
- Cleaning windows and mirrors
- Cleaning toilets
- Blank cards for additional activities

In addition to the standard procedure of participants creating a workflow for cleaning activities through ordering of the cards, the activity developed for cleaning robotisation includes the additional task of participants ranking the activities based on their personal preference and enjoyment for the specific task. This will provide designers of future robots with additional insight on which tasks would be most viable for robotisation to improve the human cleaners' work experience. In sum, this activity thus allows designers leading a participatory design workshop to better understand the context of daily cleaning work, and for participants from industry to share their thoughts about how cleaning work is done and how it could be improved.

## Usage scenarios

Scenarios for these purposes consist of narrative descriptions of fictional contexts, tasks, and the ways in which people could complete those tasks. Within design, scenarios can incorporate future technologies and their use to explore how users may interact and be impacted, providing a full description of setting, resources, and user goals (Nardi, 1992). They should be based on existing practices of users, determined for example through ethnographic studies and interviews, but also incorporate a level of creative ambition by imagining how new advanced technologies could play a role to disrupt existing systems and behaviours. Hofman and Elzen (2010) furthermore advance the notion of sociotechnical scenarios, which incorporate societal conditions as well as transition pathways for implementation of the technologies in question. As a tool for participatory value-centred design, scenarios can be used to elicit and guide discussion amongst stakeholders about desirable futures to work towards, as well as illustrating for them concrete themes that are at stake and technological pathways to invest resources in.

Three use scenarios were created for the design toolbox for responsible cleaning robotisation. The full created scenarios can be found in Appendix A. The scenarios explore the working lives of three fictional cleaning workers (Mark, Dunja, and Sven), each at different stages in their career, working at different types of clients, and working with different kinds of robots. Mark is put in charge of a robot that scrubs and vacuums the floors of large areas, which allows him to focus on easier and fun tasks, as well as connect socially with other people in the building he cleans. Dunja works with a small vacuuming and mopping robot, which she only needs to check in on when the robot has a problem, and allows her to work more freely and autonomously by choosing how she wants to approach her remaining cleaning tasks. Sven work alongside a vacuuming and dust eliminating robot, which allows him to work on tasks he enjoys and excels at, and to work faster and better to feel more competent in his work. The scenarios describe how the particular robots have changed the working practices and the overall experience of work for the cleaners. The scenarios furthermore each introduce the topics of autonomy, competence, and relatedness to readers, to familiarise them with these themes for the purposes of materials within the toolbox that follow. Thereby, the scenarios as part of a participatory design workshop introduce themes of discussion to stakeholder participants, as well as enabling a debate about desirable futures to strive for through the cleaning robotisation process.

## Provotype concept mock-ups

As suggested by Mogensen (1994), provotyping describes the use of concrete artefacts or technological concept mock-ups as a means of provoking discussion and response for new work practices, rather than as a means of guessing at or testing potential solutions to a design problem of current practices, as is generally the goal of traditional prototyping. This notion was developed by Boer and Donovan (2012) into a method for participatory

design with technological stakeholders. By having participants included in the design process, and having them engage with and respond to specially developed provocative prototypes, tensions within the technological innovation process can become clear, and it can illustrate the overall directions that stakeholders wish the technology to take. This enables collaborative analysis and exploration of the design space (Boer & Donovan, 2012).

The design toolbox for responsible cleaning robotisation includes three robot concept mock-ups, presented through ideation sketches. These concepts are shown in figures 5.1-5.3, and can be found enlarged in appendix B. Each concept was generated as an optimisation of a particular theme among autonomy, competence, and relatedness, these being basic needs for personal wellbeing as proposed by SDT (Deci & Ryan, 2012), as previously discussed in chapter 3 of this thesis. As part of a participatory design workshop, the concepts are presented to stakeholder participants, to provoke debate about these three themes and their importance for stakeholders, and to facilitate discussion about solution directions.

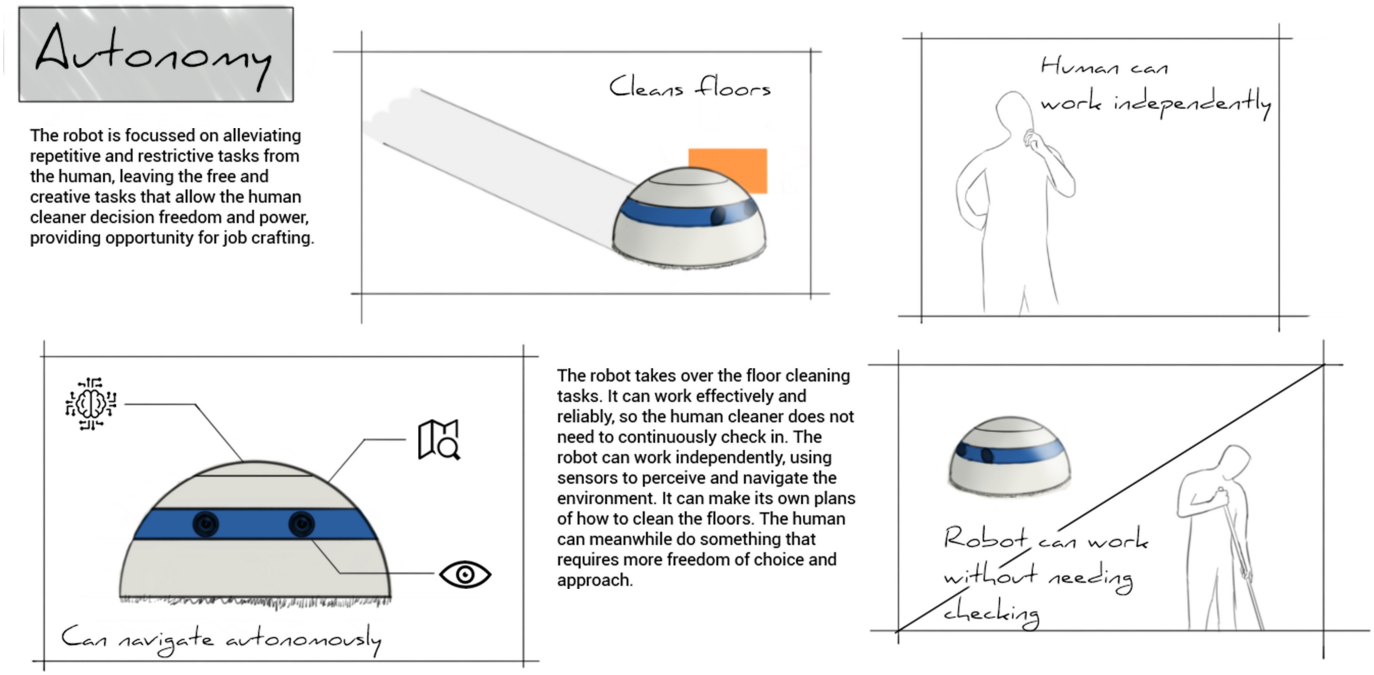


fig. 5.1. Concept ‘Autonomy’

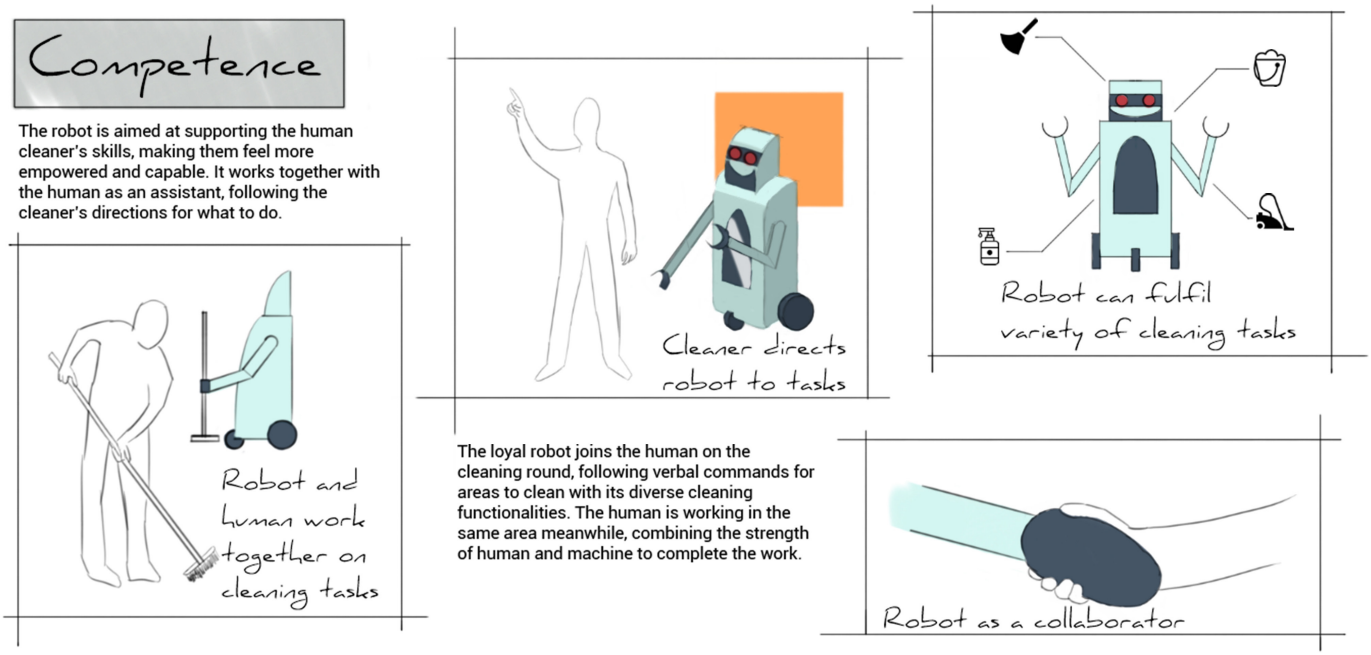


fig. 5.2. Concept 'Competence'

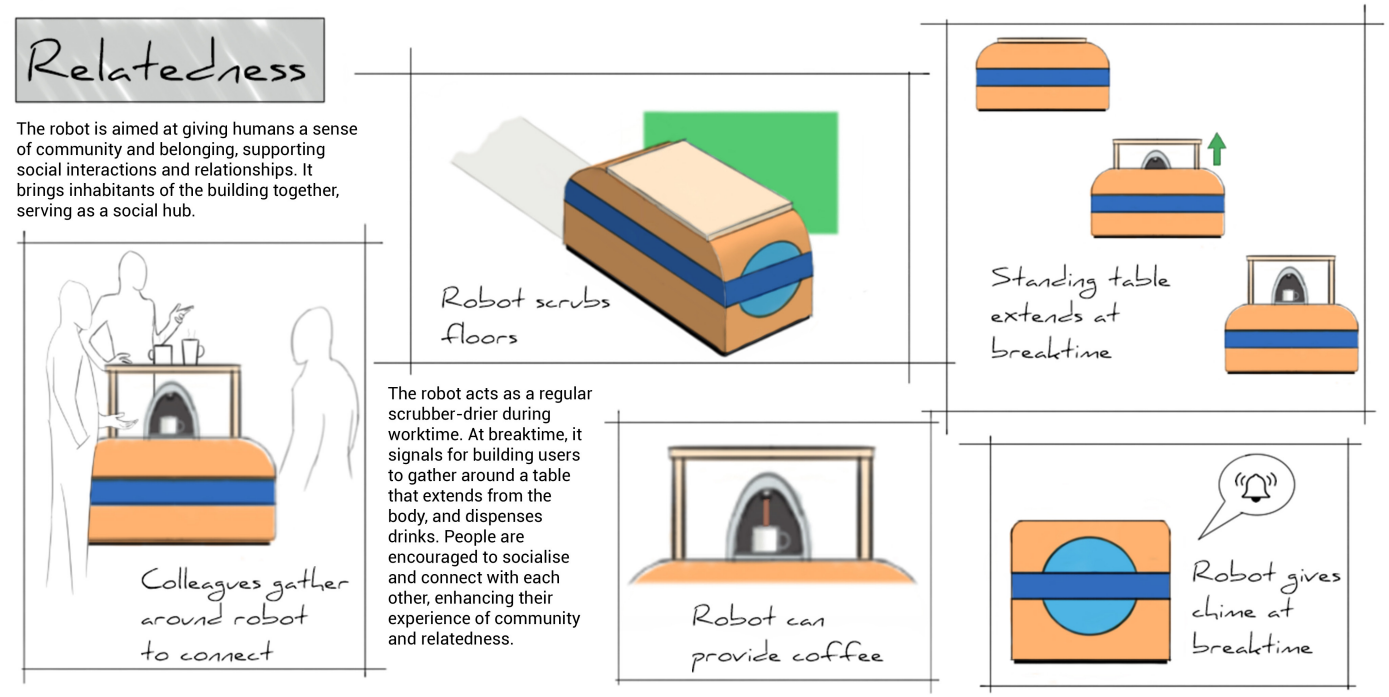


fig. 5.3. Concept 'Relatedness'

## Hierarchy roles

As discussed previously in chapter 2 of this thesis, robots can take on different roles within their relationship to humans, including their positioning within the organisational hierarchy (Dautenhahn et al., 2005; Hinds et al., 2004). According to Dixon et al. (2021), it may even be likely that future labour robots will primarily automate managerial and supervisory functions, rather than physical work tasks. Furthermore, the meaning and role assigned to robots within relationships is reliant upon the narratives that have been created to introduce them to humans (Payr, 2019). These narratives originate from for example the vision from which the robots' producers design, the way the robots are presented in marketing materials, and the way the robots are introduced to workers during training. The hierarchical role that a robot will take on within the work environment, compared to a human worker, will impact the interaction and work experience. The different potential roles possible for a robot can be presented to stakeholders through narrative scenarios, wherein different hierarchies are proposed, to elicit thoughts from them on what a suitable robot role should be. Since the goal of this method is to elicit such responses from stakeholders, there is notably a degree of overlap with the method of provotype mock-ups discussed in the previous section above.

Four mock-ups have been created for roles that a cleaning robot could take within the working environment of professional cleaning. These visualisations are shown in figures 5.4-5.7, and can be found enlarged in appendix C. In ascending hierarchical order, the cleaning robot could act as a tool utilised by the human, a subordinate that serves the human's instructions, a colleague that collaborates with the human, or a supervisor that defines and checks the human's work. The roles were chosen to represent the positions a robot can have relative to the human hierarchically, being either below, besides, or above the human, or alternatively as a tool being a use object and therefore not an autonomous actor. Moreover, the narrative mock-ups concepts are each based on the same robot with the same technical capabilities, to specifically emphasise and isolate the role that the narrative role plays on acceptance and desirability. The narratives are based on the currently existing TASKI Swingobot autonomous scrubber-drier robot (Diversey, 2021). This firstly grounds the narratives in the present, and secondly allows the narratives to be more easily understood by industry experts familiar with this type of scrubber-drier robot. As part of a participatory design workshop, the concepts are presented to stakeholder participants, to encourage discussion about the roles within the working environment, and the narrative that is seen as most desirable to strive for in the cleaning robotisation process.

## Robot puzzle

To allow stakeholders to express their visions and values for the development and implementations of new technologies, they can be enabled to participate in the ideation and conceptualisation process. In the form of design workshops, participants could for example prototype solutions and ideas that fit their values, needs, and challenges. This can take the form of rapid lo-fi prototyping methods such as paper prototyping and mock-ups (Ehn & Kyng, 2020; Rudd, Stern, & Isensee, 1996; Sefelin, Tscheligi, & Giller, 2003). Other forms of participatory ideation and prototyping include sketching sessions and storyboarding with end-users of the future technologies (Björling & Rose, 2019). For developments of future robots, such approaches could focus on task allocation (cf. Hinds et al., 2004; Ranz et al., 2017), by asking participants to consider what tasks and functions a future robot should incorporate.

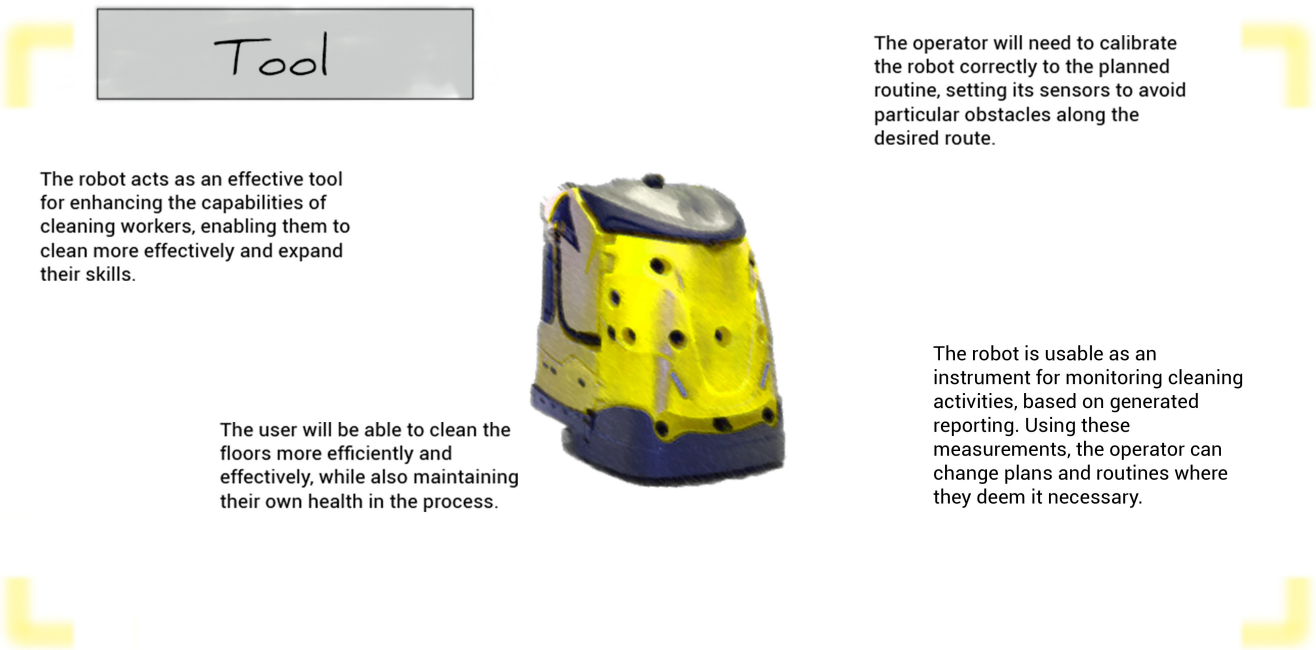


fig. 5.4. Hierarchical role ‘Tool’


fig. 5.5. Hierarchical role ‘Assistant’

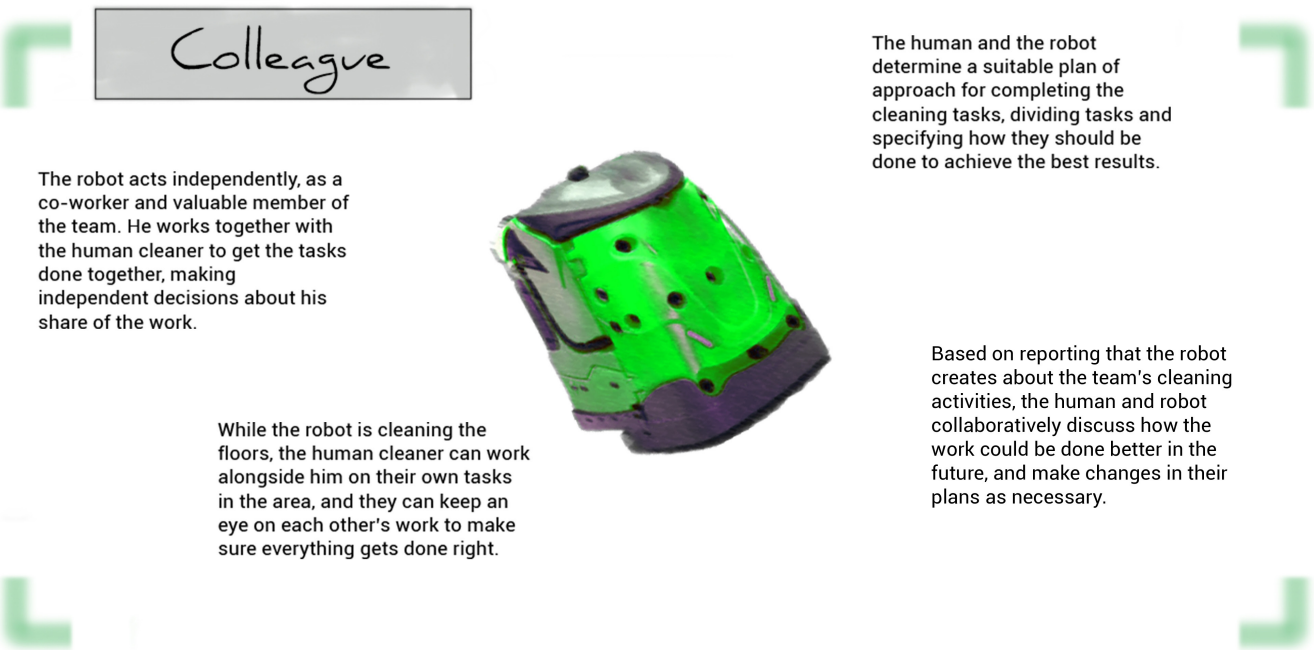


fig. 5.6. Hierarchical role ‘Colleague’


fig. 5.7. Hierarchical role ‘Supervision’

As part of the design toolbox for responsible cleaning robotisation, methods and materials have been created for an activity that will be called the 'robot puzzle,' which enables industry stakeholders to participate in the ideation and conceptual development design phases through task allocation. Workshop participants are given a visual representation of a generic 'empty' robot, as well as a selection of potential cleaning robot features and traits which they can assign to the robot. The space available for robot features is limited, and participants hence need to choose which features are most important for them and which combinations of features they deem most suitable. As iterations upon the activity, participants can in a next step be provided with a smaller robot that has less space for features, thus encouraging participants to revaluate priorities. They can moreover be given a small robot as an addition, introducing a scenario of two different robots being implemented, with different functionalities that can thereby aid the human cleaner in different ways. Two versions were created of materials for this activity in the design toolbox. A digital version was made, which can be found at https://tinyurl.com/RobotPuzzle. The digital version additionally allows for resizing of features, to indicate complexity or importance for stakeholders. An alternative printable version was similarly created, which can be found in appendix D. This version was created to allow participants to interact with the activity more freely and physically, with multiple participants being able to add and move features simultaneously. This method overall enables industry stakeholders to give their ideas for what a future cleaning robot should be capable of, and hence generates a selection of suggested features that cleaning robot designers should consider implementing in their concepts. The activity moreover enables discussion about how the envisioned robots with the selected features may specifically impact and change the nature of cleaning work for the human cleaners, whether these impacts are desirable, and how different features could interact with each other.

## Scenario cards

Scenario cards are a method for co-creation and value elicitation proposed by Alshehri, Kirkham, and Olivier (2020). They can be used in participatory workshops with societal stakeholders to discuss their interpretation and vision on a particular theme. The method can be used as part of semi-structured interviews and relies on visual cards, with illustrations that represent individual ideas or concepts within designated categories or dimensions. For example, the case study conducted by Alshehri et al. (2020) investigated Saudi women's vision on digital media, and created cards of items within the dimensions of users, technologies, and (cultural) obstacles. A card is drawn at random for each dimension to generate a scenario. In the semi-structured interview, participating stakeholders are asked to interpret the cards, and imagine a scenario based on the cards. They furthermore imagine and describe how they would act within that scenario. This process should be repeated to generate a variety of scenarios with participants, either drawing a new full set of cards or changing them one at a time. This method can thereby also be used to engage in storytelling as a collaboration between designers and stakeholders, that enables creative thinking and the seeking of specific challenges and conflicts that future technologies must address (Talgorn, Hendriks, Geurts, & Bakker, 2022).

The method of scenario cards proposed by Alshehri et al. (2020) has been adapted for use in the design toolbox for responsible cleaning robotisation. A first iteration of this method was used in a pilot workshop conducted with cleaning workers that had previous experience with an autonomous cleaning robot in their work. The full report of this pilot workshop can be found in appendix E. The pilot workshop used three decks of cards, representing robots and technologies, cleaning environments and contextual factors, and sociotechnical values. The first two decks consisted of photographs, and the third

deck with values used written phrases. It was attempted to generate scenarios and discussion through the use of these decks with the pilot participants. The method in this iteration however proved to be not as effective as intended through the workshop, as participants appeared to have difficulty discussing work contexts and technologies that differed too much from what they were familiar with, and they required more guidance in the use of this type of collaborative design tool. In response to these results from the pilot study, the method and materials were redesigned. In this second iteration, again three decks are used, which are all visual to allow for broader interpretation by workshop participants. The three decks contain representations of robotic technologies, cleaning work environments, and cleaning tasks. The environments and tasks should be relatable for workshop participants, and should therefore be adjusted for the specific work context of stakeholders. For the sake of the draft design toolbox presented in this thesis, the images focus on office cleaning environments and tasks. As part of a participatory design workshop, a card is drawn from each deck, and participants are tasked to determine how the depicted robot technology could be used to fulfil the depicted task within the depicted environment. This method thereby enables cleaning industry stakeholders to collaboratively explore with robotics designers how robot technologies can support cleaning work, and generate initial ideas for conceptual cleaning robot development.

## 5.3. Discussion

This chapter has introduced a set of design activities and tools that can be used in participatory and value-centred workshops between robot designers and professional cleaning industry stakeholders. It is worthwhile considering how these proposed design tools fit into the overarching approaches for value-centred design and responsible futuring, which were discussed at the start of this chapter. Smits et al. (2019) suggest four design phases for their ‘Values that Matter’ approach. The activities and tools contained in the toolbox presented in this chapter can be considered to best fit into the first two phases. The CUTA cards, usage scenarios, provotype concepts, and hierarchy role narratives act as the first phase, by exploring the tasks of cleaning workers, the values that are at stake, and the vision for what type of cleaning industry future is desired by stakeholders. They are thereby oriented towards reflection. The scenario cards and robot puzzle conversely act as the second phase, by envisioning how technologies can aid cleaning work in future, and what features future cleaning robots should incorporate. These parts of the toolbox are thus oriented towards generation.

Both Manders-Huits (2011) and Smits et al. (2019) have raised shortcomings and challenges in the overall approaches for VSD. The use of the proposed activities and materials could aid in overcoming these obstacles. The toolbox proposed in this chapter is unable to explicitly address the challenge of identifying all possible stakeholders to account for. However, the activities and materials have been designed with the aim of being accessible and understandable to the degree that, once identified, any type of stakeholder to the professional cleaning industry, regardless of background, should be able to participate in a workshop with the materials. They can thereby contribute to the design of future cleaning robots. It thus becomes easier to involve identified stakeholders and account for their needs.

Similarly, Manders-Huits (2011) mentioned that stakeholders can have difficulty assessing the impact of technologies on their values, and that there can be differing interpretations of values. Within the toolbox, the usage scenarios, provotype concepts, and hierarchical roles explicitly explore potential impacts of the cleaning robots on specific values, and

invite stakeholders to respond to and reflect on these impacts. They moreover introduce a shared understanding of the values at stake, to make them less abstract and vaguely defined for participants to discuss. Participants are given a specific context to consider the values in. The dynamic nature of values that Smits et al. (2019) emphasise as a challenge for VSD is not explicitly addressed by the toolbox. By introducing examples of values that could be relevant, such as SDT's autonomy, competence, and relatedness, participants may feel encouraged to discuss the meaning of those values for them personally and additionally how they expect that meaning to change in future as a result of robotisation. This will however be heavily dependent on participants.

## 5.4. Conclusions

In this chapter, we have discussed existing approaches and principles for value-centred and participatory design approaches, and proposed activities and materials for a design toolbox for responsible cleaning robotisation. The lasting effects of technology on society and the wellbeing of humans emphasises the need to design in an inclusive and responsible manner, and to consider the values that are at stake. VSD offers a theoretical framework for addressing these needs and values, which can be integrated into the engineering process to incorporate values in the design of new technologies. It is therein important to acknowledge the need for all stakeholders and their values and needs to be accounted for, and to keep in mind the dynamic nature of values. Participatory design approaches such as Responsible Futuring aim to actively involve stakeholders in the design process for new technologies that affect them, by giving them an opportunity to express their concerns and ideas, and to ensure a positive impact on society.

To aid in this participatory and responsible design process, this chapter has presented activities and materials for design workshops specifically aimed at the case of robotisation in the professional cleaning industry. Using CUTA cards, participants from cleaning industry can describe their daily practices and workflows, and indicate their preference and enjoyment of individual tasks. In three usage scenarios, potential futures of robotisation are explored, and participants are invited to reflect on and discuss the future of cleaning work they prefer. Three provotype concept mock-ups were designed, that can provoke participants to reflect on the importance and preference they ascribe to the needs for autonomy, competence, and relatedness, and to explore what solution directions they would find preferable. Similarly, four narrative mock-ups were created that describe the hierarchical role that a cleaning robot can take compared to a human cleaner, which invite participants to consider what kind of narrative they find most suitable to strive for. Using visual scenario cards, participants can generate new scenarios for how robotic technologies can aid in the fulfilment of cleaning tasks. Finally, a robot puzzle activity was created, wherein participants can in iterations assign features to a potential robot, which robot engineers should therefore consider implementing into future concepts.

Taken together, the activities and materials in the design toolbox for responsible cleaning robotisation can fit into the larger approaches for value-centred design, by inviting stakeholders to first reflect on cleaning work and the values at stake, and to then generate new ideas for how cleaning robots can support the work in future. Furthermore, the toolbox can make the cleaning robot design process more accessible for stakeholders of different backgrounds within the cleaning industry, as well as create a common understanding and platform for discussion about the values that are important within cleaning robotisation, and the ways the technology can impact those values. This chapter has thus proposed the toolbox of design materials, which shall be tested and evaluated to determine recommendations for improvement in the following chapter 6 of this thesis.

# 6. Evaluation of design toolbox for responsible cleaning robotisation

The previous chapter of this thesis has presented a design toolbox for responsible cleaning robotisation. This toolbox consists of methods and materials that can be applied for the purposes of a value-centred and participatory design workshop, aimed at supporting involvement of professional cleaning industry stakeholders in the process of cleaning robot development. To evaluate whether the proposed design toolbox meets its goals for supporting the participatory design process, and thereby acts as a practical application of value-centred design principles for the specific context of professional cleaning, it will need to be tested in practice. It must be determined whether the methods and materials successfully engage workshop participants to reflect on the values at stake in professional cleaning work, and to explore the desired impact of robotisation on those values.

The following chapter will describe two workshop sessions that evaluated the effectiveness and suitability of the toolbox, involving respectively product designers and experienced cleaning workers. It was thereby validated whether the proposed methods and materials fit with the overarching value-sensitive design and Responsible Futuring framework described at the start of chapter 5. The sessions were conducted in collaboration with the partner EngD research project, aimed at conceptualisation and prototyping of a full cleaning robot product. The workshop methodology will be described, including overall design, materials, and procedure. The results of each session will be presented, consisting of participants' direct contributions and reflections on cleaning robotisation, and an assessment of each component activity in the toolbox. These session results will be analysed, to formulate recommendations for improvement of the toolbox in future iterations.

## 6.1. Workshop 1: Designers

To evaluate the effectiveness of the proposed design toolbox for responsible cleaning robotisation, two workshop sessions were conducted. The first session was conducted with product designers. This session acted as a pilot to test the overall usability of the designed methods and materials, and to determine whether adjustments were needed for the purposes of the main workshop session with cleaning workers. In addition, the session was used to evaluate whether the materials are perceived as understandable and usable by designers. The following section will describe the overall design of the workshop, the specific materials used, and the procedure applied.

### Study design

The first workshop session acted as a pilot, to assess the overall usability of the toolbox contents and feasibility of the workshop set-up. For this session, a group of students of industrial design at the University of Twente were approached to participate in a workshop. Participants took part as a single group, and the session was overseen by two representative researchers from the two involved research projects. These facilitators guided the session along the set schedule of workshop activities, and took notes of participant responses. The session was conducted in Dutch, based on indicated preference by participants.

The session was conducted in two parts. In the first part, the focus was on exploring the topic of cleaning robotisation and the values involved. This was achieved through

the reflection activities of the CUTA cards, usage scenarios, provotype mock-ups, and hierarchy roles. The goal here was to evaluate whether the applied toolbox contents successfully facilitate discussion between participants in a workshop about their vision of cleaning work and the professional cleaning industry, and establish shared understanding of what they wish cleaning work to look like in the future. In the second part of the workshop, the focus was on generating ideas and concepts for how cleaning robots can support future cleaning work. This was achieved through the concept generation activities of the robot puzzle and scenario cards. The goal of this second part was to evaluate whether the applied toolbox contents successfully enabled participants to collaboratively take part in the concept generation process for future cleaning robots, by imagining future scenarios for robot use and assigning desired features to a potential robot.

## Materials

The session was conducted with the materials described as part of the toolbox in chapter 5 of this thesis. These materials can be found in appendices A-E of this thesis. This includes the CUTA cards, printed versions of the usage scenarios, provotype mock-ups, and hierarchical role narratives, the three decks of scenario cards, and the robot puzzle. For the robot puzzle, the pilot session with designers made use of the digital version of the materials. Participants were enabled and invited to handle the materials provided themselves, and the room included a whiteboard where both participants and session facilitators could write down ideas and notes. There was also a projector screen to share visual information.

## Procedure

The workshop started with an introductory presentation from the facilitating researchers. Participants were informed about the background and goals of the involved research projects. It was explained that the projects aim to facilitate a healthier and more satisfying work experience for professional cleaning workers in the future through robotics innovations. Participants were told about the specific goals of the session, namely to collaboratively discuss and generate ideas about cleaning robotisation, through various design activities. The general timeplan for the session was given.

The first activity used the CUTA cards. Participants were asked to use the cards to imagine the workflow of a regular cleaning worker as it exists currently, and to consider how this situation could be improved. They furthermore ranked each cleaning activity on the cards according to whether they expected the tasks to offer enjoyment, and discussed why.

Next, the usage scenarios were presented and reflected on. Participants were each given copies of the written scenarios, and had time to read these by themselves. Once they finished reading, a collective discussion of the scenarios took place. They were asked to discuss for example which scenario they deemed most desirable, specific elements they found noteworthy or important, and how they expected the scenarios might affect certain personal values.

Participants were then asked to evaluate and reflect on the provotype mock-ups. Printed copies of the robot sketches were placed on the whiteboard, and the facilitating researchers gave a short presentation describing each concept and its intended effects. Participants were given the opportunity to study the mock-ups more closely, and to ask questions. They were then asked to reflect and discuss their thoughts about the robot concepts, including for example which concept would be most desirable, and what values a future robot should emphasise to be most acceptable and effective in their opinion.

After the provotypes, the hierarchy role narratives were presented. The narrative visualisations were placed on the whiteboard, and the facilitating researchers gave a short presentation explaining them. Participants could read about the roles more closely, and ask questions. They were asked to reflect and discuss their thoughts on the potential hierarchical roles that a cleaning robot could take, including for example which role they would deem most suitable, and how the roles might affect the most important values in cleaning work.

Participants were at this stage in the sessions given a break for lunch.

Next, the robot puzzle was used. Participants were shown the digital version of the puzzle activity on the projector screen, and could indicate which functions should be inserted in the robot, and at what size. They were asked to choose the functions they would like to include in a future cleaning robot, and discuss amongst themselves reasons for why the thereby proposed robot would offer considerable added value for a better future of cleaning work.

The scenario cards were used as the final activity of the session. The facilitating researchers gave a brief explanation of the activity, and participants were then shown the three decks of cards. A card was drawn from each deck, and participants were asked to describe how the depicted cleaning goal could be achieved in the depicted context environment with aid of the depicted robotic technology. They could then discuss different interpretations of such scenarios, and whether the scenario would be desirable and useful. This process was repeated over iterations, with new cards being drawn from each deck, to create and discuss multiple scenarios.

The session was closed with a debriefing of the participants, concluding remarks and additions from participants, and a short reflection of what they overall thought of the session, the activities, and the materials. The goals of the session were reiterated, and general first apparent results and conclusions were summarised. Participants were informed about the next steps in the involved research projects. Finally, the participants were thanked for their contributions, and given the opportunity to ask any remaining questions about the research.

## Results

The results of the pilot workshop with designers will be described in the following section. The results have been structured based on the individual activities of the workshop. The overall results of each respective activity are described, and each corresponding component of the toolbox will be evaluated regarding their usability for collaborative design with cleaning industry stakeholders, specifically cleaning workers.

### CUTA

Participants used this activity to immerse themselves in the daily routines of professional cleaning workers, by imagining a suitable workflow for the provided cleaning tasks. They furthermore used it to discuss which activities they would imagine to be unpleasant, and suitable for robotisation. Through the activity, they noticed shortcomings, such as that they expected cleaning of spaces should occur in cycles throughout the day, for example by repeating each activity in a pattern across multiple rooms in an office building. They expected that cleaners will clean furniture, clean touch-surfaces, vacuum floors, and clean difficult corners in a single room, and then move to the next room to do so again. However, other activities such as clearing trash bins, scrubbing floors, cleaning toilets, and cleaning windows, they assumed will be done with all rooms at once.

As they took part in this process, participants noted that they thought this activity a good

way of starting the conversation, and exploring the context of cleaning. It made them reconsider their expectations, and specify their internal scenarios of how cleaning is really done in practice. The method was hence deemed effective for making engineers understand the detailed tasks that a cleaner must perform. Moreover, it was seen as a good way to create a common understanding of what cleaning work entails, which can ease discussion in a workshop session with diverse stakeholders from the professional cleaning industry.

### Usage scenarios

Participants read the provided scenarios for themselves, and made several observations about the situations described. They described how the interactions with the robots differed between the scenarios, particularly in regards to the amount and type of supervision the robots require from human cleaners. They discussed how these differences will change the work experience for cleaners. Participants also noted differences between the tasks the robots perform, and the skills they require from cleaners. They hypothesised that it might be satisfying for cleaners to learn new skills, although it would be dependent on individuals whether they decided to work in cleaning in order to learn. The new skills can however make the work more attractive to newcomers to the industry.

In regards to the method, participants wondered if the scenarios changed too many variables, as they depict situations in different types of building, cleaners with different years of experience, robots with different capabilities, and cleaners with different attitudes. There were also questions about whether certain responses to and impacts of the robots should be prescribed within the scenarios, such as one scenario explicitly mentioning that there are more opportunities for social engagement as a result of the robot. Finally, there was discussion whether the details and nuances of the scenarios are clear and understandable for readers from the cleaning industry. The overall conclusion was that due to their experience and expertise with current cleaning work, such participants should have a strong understanding of how the work is done and how robots could change the work.

### Provotype concept mock-ups

Participants used this activity to consider how different types of robots, as depicted in the provotype mock-ups (figure 6.1.) could affect the values apparent in cleaning workers' daily experience. This focussed specifically on the three core wellbeing needs from SDT, that is to say autonomy, competence, and relatedness, which the provotypes were based on. They noted different levels of realism and implementability between the proposed concepts, with most being likely too advanced to be easily realised with current technologies. They did not specify a particular preference for any of the shown concepts or directions. During this activity, the participants questioned whether a robot should already be prescribed as the solution for the challenges faced by the cleaning industry. They discussed whether this could lead to the exclusion of alternative solutions and technologies from consideration in the design process.

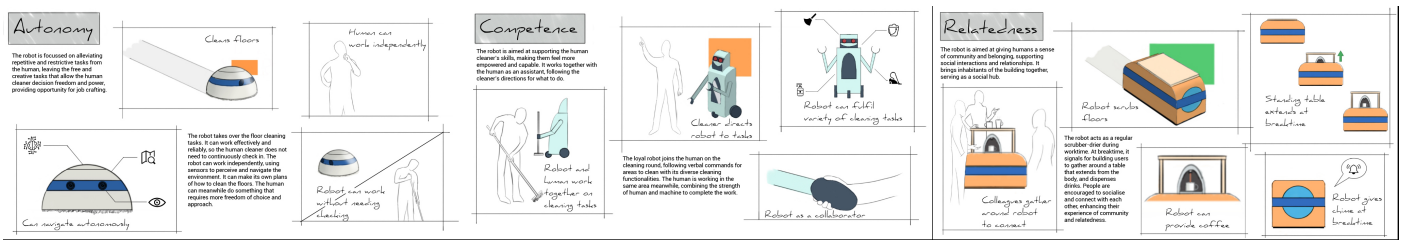


fig. 6.1. Provotype concept mock-ups

The participants liked that the mock-ups were visual, as they expected that this would make them more understandable and accessible for cleaning workers and other industry stakeholders. They did offer the suggestion to clarify the context and setting of the sketches, specifically by adding backgrounds to the mock-ups. This would clarify how the robot would be used, and also indicate the size of the robots based on scale.

**Hierarchy roles**

Participants used the provided narratives (figure 6.2.) to consider how a robot can fit into the proposed roles within their relationship to human cleaning workers. They reflected on how certain design decisions and nuances in concept presentation may influence how a robot is perceived and what role it may take. There was some scepticism towards the notion of a robot taking the role of supervisor or manager, but overall no explicit preference was given for a particular narrative to follow, and it was instead seen as something to consider on a case-by-case basis and in conversation with end-users.

It was noted that terms such as ‘colleague’ can be open to interpretation, which can cause misunderstanding when doing activities such as this with cleaning industry stakeholders. The participants similarly suggested that the language used for the narratives may be too complex for target groups such as cleaning workers. There may also be overlap with the usage scenarios that were used previously, with similar themes being discussed, which might be seen as repetitive by industry participants. One participant observed that this method may rely too much on reading, and that it would be better to give industry participants a physical activity they can do with their hands. Overall, due to the apparent complexity and topics, they suggested this activity might be more appropriate for a workshop session with managers and employers in the industry, rather than cleaning workers. In such a session, they suggested it should furthermore be made explicit that the narratives represent an upwards scale of autonomy and hierarchy for the robot, as the robot becomes increasingly dominant over the human if it shifts from tool, to assistant, to colleague, and finally to supervisor.


fig. 6.2. Hierarchy roles

### Robot puzzle

Participants mainly experimented with the functionality of the application during this part of the session, rather than generating a concrete robot concept of functions. They did use it to reflect on what potential functions a robot could fulfil within cleaning, including assessing whether the materials were missing any features. They considered how many features could feasibly be implemented in a single robot.

Participants questioned whether industry stakeholders will be able to understand what would be 'realistic' for a robot to be able to do. They expressed concern that with the option available to participants in the puzzle's digital version, industry participants may make functions as small as possible to fit as many as possible into a single robot, thereby resulting in a robot concept that cannot be feasibly developed and implemented. They noticed that in the digital version, the functions are shown in a scrambled order, and suggested to give the ordering a clearer structure to make it easier for participants to find specific functions. Finally, the participants suggested this activity could be more effective using a physical version of the puzzle, to give it more interactivity for industry participants.

### Scenario cards

The participants used the scenario cards to imagine ways a particular robot or technology could support in fulfilling certain cleaning goals. As cards were drawn, they created new scenarios based on the generated combinations. This enabled them to explore specifically detailed context situations of professional cleaning work, to consider how a robot could add value. Multiple iterations of scenarios were in this way generated. Using their own creative capabilities as product designers, participants were able to imagine innovative robotic solutions to the cleaning challenges that the scenarios proposed.

Participants noted that certain combinations of cards proved more difficult than others to create a feasible and practical scenario, wherein the posed technology offers added value for the given context and goal. Particularly the technology cards were perceived as sometimes challenging to determine a suitable implementation for. They for example found it difficult to imagine a scenario wherein a flying drone could help when emptying trash bins. Related to these apparent challenges, participants had concern that this method's effectiveness would be highly dependent on the creative capabilities of participants. Generating scenarios and ideas in this manner can be challenging for some people, including certain industry stakeholders. This could limit the success of this particular activity.

### Debrief and post-workshop discussion

Overall, participants indicated they found the sessions useful and understandable. They expressed it gave them new understanding of the work practices, situations, and challenges of professional cleaning workers. It furthermore allowed them to explore certain ideas for how technologies like cleaning robots could offer improvements for cleaning work, but also impact values such as work satisfaction. They did feel certain doubts whether all activities would be effective with participants from cleaning industry, particularly cleaning workers.

## Adapted workshop approach

Based on the results of the pilot session conducted with designers, changes were made to the materials and activities that would be used in the main session with cleaning workers. The explanations given for each activity and method were adjusted, based on the participants' feedback, to make them more accessible and clearer for the target group of cleaning workers. The participants' feedback on the hierarchy roles narratives strongly

indicated that the language and theory used in the materials would in their opinion be too complex, and would be unable to facilitate a useful discussion. The decision was hence made to not use these narratives in the main workshop session with cleaning workers. Finally, in response to the feedback on the robot puzzle task, the main evaluation workshop with cleaning workers would be using the physical iteration of the workshop materials for that activity. Through these adaptations, the workshop was developed to be more accessible and effective for application in the main workshop session.

## 6.2. Workshop 2: Cleaning workers

The second workshop session acted as the main evaluation of the proposed design toolbox, and was conducted with a group of cleaning workers. The goal of this session was to use the toolbox's components to collaboratively explore context and important values in professional cleaning work and cleaning robotisation, and to give participants the opportunity to contribute to the robotisation design process. The session thereby furthermore evaluated whether the proposed toolbox successfully enables cleaning industry participants to discuss their values, concerns, and ideas, and to participate in the design process. The following section will describe the design of the workshop, materials, and the procedure for the workshop with cleaning workers, with a focus on changes made based on the results of the pilot workshop with designers.

### Study design

For the main workshop session, to assess whether the toolbox meets its goals for supporting value-based design, a group of cleaning workers were approached to participate, through contact with their cleaning employer. The participating cleaning workers were all engaged at the University of Twente to clean campus buildings. They participated as a single group, and the session was again overseen by two representatives from the involved research projects. The session was again conducted in Dutch, based on participants' preferences.

The session followed a structure similar to the pilot workshop, being conducted in two parts oriented towards reflection and collaborative concept generation. The first part used the CUTA cards, usage scenarios, and provotype mock-ups. The second part of the session used the robot puzzle and scenario cards. Based on the results of the pilot session conducted with designers, changes were made to the materials and activities that would be used in the main session with cleaning workers. The explanations given for each activity and method were adjusted, based on the feedback, to make them more accessible and clearer for the target group of cleaning workers.

### Materials

The main evaluation session with cleaning used broadly the same materials as used in the pilot workshop and as described in chapter 5 of this thesis, with two exceptions. The results of the pilot workshop indicated that the materials used for the hierarchy roles narratives relied too heavily on complex theory and language. It was hence concluded that these materials would be unable to facilitate a feasible discussion, and would therefore not be used in the main workshop session with cleaning workers. Furthermore, the results of the robot puzzle task in the pilot workshop suggested the use of physical materials that also standardised the size of functions. Therefore, the main evaluation workshop with cleaning workers would be using the physical iteration of the workshop materials for that activity. The main workshop session used the same space as was used for the pilot workshop, and again included opportunities for sharing physical and digital notes through a whiteboard and projector.

## Procedure

The session followed the procedure and timeplan that was previously described for the pilot workshop, with the aforementioned exceptions of removing the hierarchy roles activity and using the physical iteration of the robot puzzle rather than the digital. For the CUTA cards activity, the participating cleaning workers were asked to describe their own current experience using the cards, by placing them in the correct order, and discussing amongst themselves differences in their approach towards cleaning spaces. They furthermore also ranked each cleaning activity on the cards based on how much they enjoyed it, and discussed why.

## Results

The following will describe the results of the main workshop with cleaning workers. The results have been structured based on the individual activities. The general results of each activity are described, as well as their implications for the values at stake in cleaning robotisation, and an evaluation of the respective activity's effectiveness within the toolbox.

### CUTA

Participants performed this task as two groups, to generate two workflows for cleaning tasks (figure 6.3.). As they used the CUTA task cards to order their workflows, they talked amongst themselves about differences in their approaches to daily cleaning. Participants explained that certain tasks, such as scrubbing floors or cleaning windows, they were not personally responsible for in their daily work. For others, these tasks are part the contracted task assignments. This caused discussion and description of what each participant's contracted tasks were, and what guidelines they follow therein, such as not cleaning anything that is higher than two meters. There were also differences in what order they performed their cleaning tasks in, as some chose to start with clearing rubbish bins and cleaning furniture, whereas others started with cleaning of touch surfaces and


fig. 6.3. Participants creating CUTA workflows

the removal of cobwebs. After describing their workflows, the participants next ranked each of the tasks based on enjoyment. The cleaning of touch surfaces was expressed to be bothersome. They indicated that it is a lot of work, because people touch a lot of places, at times unnecessarily, such as opening doors by pushing against them rather than using the door handles. They hence found it additionally frustrating that that work is the result of other people's misbehaviour. Toilets and bathroom cleaning was similarly considered very unenjoyable, because it is filthy, and once again at times exacerbated by misbehaviour from other people, such as throwing food and drinks away there. Conversely, the cleaning of furniture such as tables was considered as comparatively more satisfying. They explained that furniture cleaning often has the most noticeable results, as the area becomes visibly cleaner, which gives them the feeling they are making a significant contribution. Similarly, these results are therefore also more likely to be noticed by other people within the environment, who will express their gratitude which makes the cleaners feel more satisfied. They explained that work enjoyment is furthermore dependent on how much time they are given for certain tasks. If they are given additional time for cleaning certain areas, they feel like they do not need to rush to complete their work, and the work thereby becomes less stressful and more enjoyable. Finally, they expressed that overall they find smaller office spaces to be more enjoyable to clean compared to larger corridors and halls, since the latter often requires longer periods of the same tasks, which becomes repetitive.

This activity firstly revealed that participants valued working based on their specified personal responsibilities and fulfilling their assignments, in accordance to the agreements made in their contracts. They expressed this by discussing with each other what tasks were part of their core agreed assignments, and how their assigned tasks differed and what this meant for them. Conversely, the participants were frustrated by the lack of personal responsibility from other building users, who display misbehaviour and produce additional dirt that must be cleaned. Generally, the participants emphasised the value and importance of internal and external satisfaction as a result of their work, as there needs to be positivity. They wanted there to be gratitude and appreciation of their work. Their discussion about getting sufficient time for their assigned cleaning tasks furthermore indicated that they preferred their work to not be too stressful or rushed, so that it can completed comfortably but effectively. This thereby also relates to a need for a sense of competence, as SDT would describe it.

The CUTA method effectively prompted participants to describe their current experience of cleaning work, and thereby collaboratively explore the context in which cleaning robots will be implemented. This created suitable common foundation for more in-depth discussions in the activities that would follow in the workshop session. It furthermore sparked discussion about participants' differing experiences and perspectives on the work, such as comparing differences in the tasks they are contracted to perform, and preferred ordering of tasks. This revealed that all participants had their own preferred cleaning approaches and tasks. Regarding task preference, the activity of ranking the CUTA tasks cards based on enjoyment encouraged participants to discuss aspects they liked and disliked in their work. This also revealed values that participants deemed important.

**Usage scenarios**

The participants read each of the provided scenarios, and gave their reflections. They expressed that all scenarios represented an improvement on their current situation of daily cleaning work. According to them, a cleaning robot should function automatically, rather than being remotely controlled. They described the scenario of Dunja as the most desirable, which is the scenario that has a robot that can fulfil various floor-cleaning

tasks independently without constant human supervision. They liked that the robot in the scenario can perform tasks low on the ground, so that the human cleaner can remain working at eye-height. There was mild concern that signals a robot gives about needing intervention from the human cleaner could be annoying, though this would be dependent on how often these situations occur. Participants more generally indicated that they would like to take responsibility and play a role in the 'teaching' process for robots, that is to say instructing the robot what tasks to fulfil and how those tasks should be fulfilled. This is because a cleaner has the needed experience to judge what is required to clean a specific building or space, and knows what resources to use for this. More generally, they did caution that not all of their colleagues may want, or dare, to take responsibility for an advanced cleaning robot, for example due to fears for technical complexity or because it is an expensive piece of equipment. People will need to get used to new routines when a robot is implemented, which will require time that the implementation process must account for. They consider a robot as primarily a tool or piece of equipment, but some did express an interest in the idea that a robot could make sounds or 'talk' when it is near the human cleaner. Robots should not lead to workers losing their jobs. Rather, it would be ideal if a robot can act as a support for new employees in the industry, to help them work healthily and obtain the skills they need. Participants expressed that, to them, social contact with colleagues and other people in the space being cleaned is what makes cleaning work truly fun. There is a need for a strong sense of teamwork and community amongst the cleaning colleagues, and a robot should not break or obstruct this. In response to the scenarios, they raised the possibility that a robot can lead to more social interaction between the human cleaner and other people in the cleaning space. This could occur for example by sparking curiosity in bystanders who start conversations with the cleaner to ask how the robot works. They expected however that this will depend on the personality and interests of those bystanders. For example, the technical students and researchers the participants encountered in their regular work would likely have increased interest in a robot due to their technical background, and therefore be likelier to start a conversation with the cleaner about it. Conversely, there may be comparatively less social engagement from bystanders from non-technical and non-academic backgrounds.

The participants' responses about a future robot needing to function automatically, with as little need for human intervention as possible, can be related to values of independence and personal autonomy. The cleaners wished to be able to focus on their own tasks, rather than constantly check in on the robot's performance, and help it in case of problems. Participants expressed that regarding values of trust, they place greater confidence in themselves than in a robot, because they know they can depend on their own capabilities. Such trust must therefore still be built by future robots, even if it becomes technically feasible to make them semi-autonomous with reduced need for human supervision. The role the participants envisioned for cleaners in the teaching process for robots reiterates the aforementioned value of autonomy, and moreover introduces topics such as personal empowerment and having the cleaners' hands-on expertise with cleaning be acknowledged. If robots can take a supporting role for new employees in the cleaning industry, as the participants proposed, this would strengthen values of personal growth, as well as health. Finally, the emphasis that participants placed on the social engagement, with colleagues, other building users, and even a robot, indicates they strongly value social interaction, a sense of community, and a need for relatedness, as SDT would describe it.

From a methodological standpoint, this activity was effective at triggering discussion and reflection by the participants about their desired future vision for cleaning work, and the values and topics that must be accounted for in robotisation. Regarding usability of the materials, participants appeared capable of handling the amount of reading and analysis

required to engage with the scenarios, and could when needed refer to their own copies to re-read details during the discussions. Participants did appear to have the impression that the scenarios, and specifically the robots therein presented, were currently feasible from a technological standpoint. One participant for example during the reading expressed she was not aware that these robots are currently possible. Related to this, they also at times appeared to rely on the scenarios to prescribe their own opinion or thoughts on how the presented robots could impact their work. For example, when asked how the robot in a scenario could improve the experience of cleaning work, they cited the opinion of the fictional cleaning worker that the scenario described, rather than evaluating the robot based on their own situations and beliefs.

**Provotype concept mock-ups**

The participants studied the mock-ups that were presented, and discussed their opinions (figure 6.4.). Based on the concepts shown, they expressed a preference for robots that can fulfil a wide variety of cleaning tasks (semi-)autonomously. There was debate between participants about the preferability of robots having more animated or anthropomorphised appearances, as is the case with the competence provotype (see figure 6.1.). Some participants liked that a robot can have a humanoid character, and can be like a friendly companion that walks alongside the cleaner, whereas others wanted a robot that is purely function-oriented in its appearances and work approach. Participants also liked the idea of a robot that stimulates relatedness and interaction between the different people in the cleaning environment, including other building occupants. Based on the mock-ups, participants shared a vision and expectation that cleaning work in the future will become mainly a secondary side-job, that workers do alongside their studies, so that they can learn skills for better and more profitable jobs. Participants believe robots can facilitate this shift.


fig. 6.4. Participants discussing provotype mock-ups

These results indicate that participants firstly value independence, as they preferred a robot they can assign as many tasks as possible to do autonomously, so that they themselves could do their own tasks undisturbed. Participants disagreed whether a robot can and should provide social engagement and companionship, to form social bonds between the human and the robot. However, they did collectively like the notion of a robot strengthening the relatedness and social connections between humans. Through their vision of cleaning becoming a secondary job, participants finally also expressed the values ambition and growth, by proposing a shift in the industry that allows workers to move into new occupations.

This activity enabled discussion about what type of robots the participants would want to see in future, and what the capabilities and goals of such robots should be. These discussions moreover revealed values of independence, social engagement, and ambition, which the participants deemed important and relevant. Participants appeared to find the mock-ups understandable and clear. However, similar to the usage scenarios, it did appear that participants had the expectation that the presented robots were feasible product concepts that could currently be produced. In other words, they may have interpreted the mock-ups as representing regular concept proposals, rather than provocative designs meant to trigger reflection. This may therefore have created incorrect expectations in the participants for what type of robots will be produced in the near future.

**Robot puzzle**

Similarly to the CUTA task, the participants divided into two groups to try the robot puzzle (figure 6.5.). They were initially given the physical copies of the regularly sized robot template. The groups assigned fairly similar features to the robot through the activity, giving the robot functions to fulfil tasks related to cleaning of floors, windows, and bathrooms. These were notably the tasks that were ranked as least enjoyable previously in the CUTA task of the session. Both groups also gave the robot navigational capabilities, to avoid obstacles and humans and to move across stairs. Finally, both groups gave their robot the functionality to play music, which they described as way to make the work less boring. Participants were then given the smaller-sized robot template, to make them remove or re-evaluate features, based on their personal priorities and preferences. They assigned these smaller robots features similar to their initial choices, with primarily functions for cleaning of floors and bathrooms. One group also once more gave the robot a feature for playing music. As the final iteration of this activity, the participants were given a last small robot to assemble with new features alongside their second concept. Both groups used this to have the smallest robot perform the floor and bathroom cleaning tasks, whereas the larger robot would perform miscellaneous tasks such as cleaning windows, emptying trash bins, dusting, and playing music (figure 6.6.).

Based on the tasks the participants assigned to the respective robots, that is to say floor and bathroom cleaning, it is firstly apparent that workload reduction was an important goal for them, in order to allow them to have a more comfortable work experience. Moreover, the fact that these tasks aligned with the rankings performed as part of the CUTA activity, indicates that they wished to optimise the value of work enjoyment, by having the robot take over work that they did not enjoy. Similarly, the choice of one participant group to enable each iteration of the robots to be able to play music came as a result of them wanting to reduce boredom, and thereby increase fun and enjoyment for themselves during cleaning work.

This method resulted in a useful discussion of participants' priorities and preferences regarding the tasks and functions that a future cleaning robot must be able to perform. The activity revealed differences in priorities between different participants, as some

emphasised the need for a robot to fulfil a variety of cleaning tasks effectively, whereas others maintained a preference for features like music. It was noteworthy during the session that when participants were given the smaller robots to assign features to, they mainly considered the functions they had placed into their previous concept, rather than evaluating whether it could be appropriate to add new features. Moreover, they appeared to not consciously take into account the interaction and relation between different features, and how these would form a coherent whole. As a result, the assembled puzzles became primarily a list of features that participants thought should be prioritised, rather than full concepts.

**Scenario cards**

The participants were given a brief explanation of the scenario cards, and differences between the decks. Following this, a card was randomly drawn from each deck to act as prompts for the scenarios. Based on these, participants mainly focussed on the depicted environments and cleaning tasks, and shared stories about cleaning such environments, from either their personal experiences or experiences they knew of friends and colleagues. These anecdotes described the routines and challenges involved in cleaning the depicted types of environments.

The stories and anecdotes that participants shared in response to the scenario cards did not strongly reveal new values and themes to account for in robot development. They shared experiences of cleaning large open spaces, and the repetitive and monotonous nature of tasks those environments require, which they would like to see reduced in future. Similarly, their responses reiterated previous frustrations with other people's behaviour, such as overstuffing trash bins, which they would like to change as a result of cleaning work being more visible and appreciated.

fig. 6.5. Participants assembling the robot puzzle

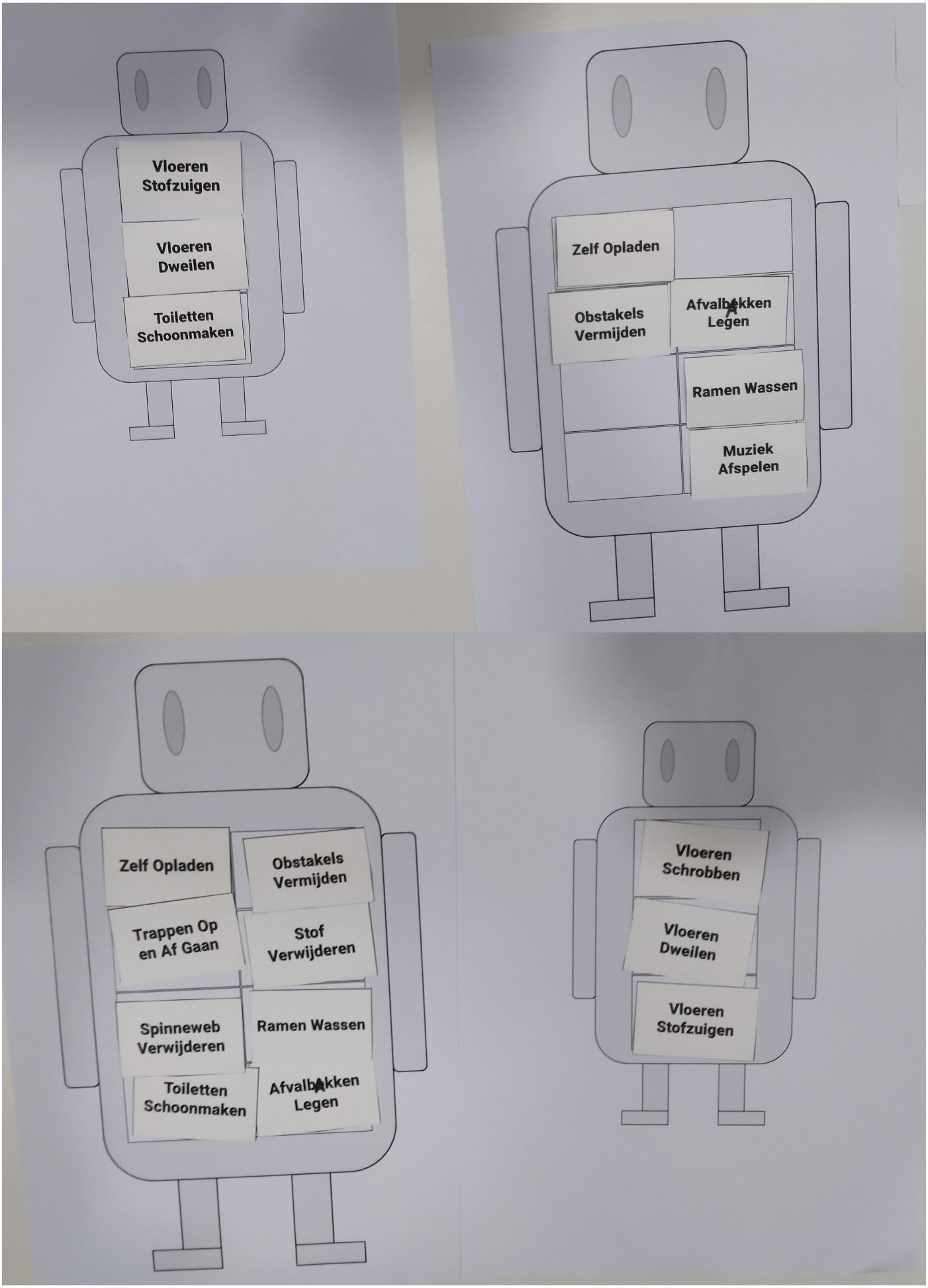


fig. 6.6. Final robot puzzle assemblies

Participants overall appeared to have difficulty with these materials, which limited the effectiveness of this activity. They found it challenging to recognise which of the cards referred to a context and which depicted a cleaning goal, since certain cards appeared to potentially depict both. Furthermore, the participant responses as mentioned tended towards personal stories and anecdotes, rather than generating new scenarios and situations wherein a future robot could play a role. Overall, this method did not successfully meet its intended effects.

**Debrief and post-workshop discussion**

In the closing discussion and reflection of the session, participants expressed firstly enjoyment with the workshop and activities, and that they felt able to share their ideas and concerns. Moreover, they indicated the session gave them personally new ideas for how cleaning work could change in future, and the role that robots could play. The session allowed them to explore the different perspectives of their colleagues on robotisation of the industry, which provided new insights and understanding for them. They expressed they very much enjoyed the discussions that were created through the activities that were part of the workshop. Finally, when asked for their opinions on the workshop materials, they shared that they found everything largely clear and understandable, combined with the explanations given by the facilitating researchers.

## 6.3. Discussion

The workshop sessions described above were used to evaluate the effectiveness of the design toolbox for responsible cleaning robotisation. Based on the results, each component of the toolbox can be assessed, and recommendations made for further improvement of the respective tools and the toolbox as a whole.

The CUTA cards method has been shown to effectively engage cleaning industry participants to share their workflows and approaches towards daily cleaning work, and thereby also discuss their experiences differed from each other. The additional activity of ranking the tasks according to participants' enjoyment moreover elicited discussion about which aspects of cleaning work are experienced as more or less pleasant. This method overall thus revealed and explored multiple values that participants deemed important, and should hence be incorporated in future robotisation. Since the ranking activity appeared to be most fruitful in regards to exploring values, future iterations on this component of the toolbox could add additional ranking tasks on new axes, such as based on time consumption or workload required. This could stimulate new types of discussions, and thereby reveal other themes and values to account for in cleaning robot design. The main activity of the CUTA method, of generating daily workflows, should however always be maintained, since it serves an essential role of grounding discussion through the overall workshop session in a common understanding of what cleaning work entails.

The usage scenarios of the toolbox successfully generated discussion about the participants' vision for future cleaning work that includes cleaning robots, and the effects those robots can have on workers. It enabled them to compare different directions that future robotisation could take, and to compare the desirability of those presented scenarios. These discussions allowed participants to express additional values to design for, such as trust and independence. It also led the participating cleaning workers to describe how they envision a role for themselves and their colleagues in the robotisation process. A potential risk for this methodology, that became apparent in the evaluations, was that participants could have gotten inaccurate expectations of the current technical capabilities of robots, as they interpreted the scenarios as currently feasible. Moreover, the scenarios included

examples for the impacts that the respectively described robots could have on cleaning workers and their values. This has the risk of steering discussions and responses, as participants in the workshop at times chose to repeat the concerning passages from the scenarios, rather than evaluating the described robots and their impacts from their own perspective. Future iterations on these scenarios should therefore investigate a suitable balance between these prescriptive examples, which enable participants to understand how their values may be impacted, and more open-ended descriptions, which encourage participants to imagine their own impacts.

The provotype concept mock-ups prompted reflections from participants on what future robots should be capable of, as well as the potential interactions cleaners could have with robots and the impact thereof in the future. The participating workers used the mock-ups as inspiration to discuss the desirability of social features and anthropomorphic styling of the robot. Similarly, it induced the participants to fully describe and explore their vision for cleaning becoming a side-job, facilitated by robots. By creating these discussions, the provotype mock-ups as a method were effective at revealing and exploring the participants' values, as well as their wishes for improvement in future cleaning work. The materials were clear and understandable for participants, making the ensuing discussion accessible. Iteration on these materials could expand on the presentation of the current or new provotype concepts, by for example producing more expansive illustrations with detailed use scenarios, or building physical representations of the concepts, with lo-fi functionality, to enable hands-on experimentation during a workshop.

The hierarchy role narratives were only applied in the pilot workshop with designers. The materials in that session created discussion about how a robot as presented could embody the respective roles, and how these roles are affected by design decisions. They considered these roles as a topic that should be discussed and considered as part of the design of future robots, and the narratives effectively facilitated such reflection for designers. The language and theory used was however evaluated as being too complex, thereby making the materials unsuitable for a target group of cleaning workers. Future workshops could evaluate whether the materials could be effective for application with other target groups, such as cleaning company management and organisational experts. Alternatively, the narratives could be redeveloped with more accessible language, and with clearer explanation of the theory underlying them, to make them suitable for a wider target group of industry stakeholders. A final option is to keep the hierarchy narratives as a part of the toolbox purely for use by robot designers, as a means of reflecting on the social and hierarchical role they are envisioning for their future cleaning robots.

The robot puzzle succeeded in having participants consider the specific features they would wish to assign to future cleaning robots, as well as the priorities for those features. It furthermore encouraged discussion between participants about their differing opinions regarding what features a robot should have, beyond the immediate fulfilment of particular cleaning tasks. The method however did not meet its full scope of having participants generate a holistic robot concept, with consideration for the interactions between different functions and features, and consideration for how the envisioned concept as a whole would impact cleaning work. To improve upon this, future iterations upon the materials and activity could explicitly incorporate and call attention to the interactions between different envisioned features, to make this a topic of discussion between participants. Moreover, a means should be sought for developing the prioritised functional lists that currently resulted from the method, into more concrete robot concepts, that participants could then reflect on and that robot designers could further develop.

The scenario cards method had the designers conceptualise ideas for how certain robot technologies could aid in various cleaning tasks, whereas cleaning workers used the

activity as an opportunity to reflect on personal cleaning experiences with depicted environments. The cards were overall not effective at fulfilling their intended goals of generating new scenarios and concepts through participation of cleaning workers and other stakeholders. The workers tended towards past anecdotes and stories, rather than conceptualising ideas for future concepts. They moreover had difficulty distinguishing the meaning of the card images, and determining whether they were supposed to represent context or goals. This indicates the chosen images were too unclear or open-ended, and their role as either a context or goal should be made more unambiguous. It could be worthwhile to re-evaluate this activity using new cards, based on images that more clearly communicate their meaning. One possibility could be using photographs provided by participants themselves, as these will inherently convey particular meaning or experience. Furthermore, the method of scenario cards could be deemed as unsuitable for the planned purpose of generating future scenarios and concepts, and could instead be used earlier within workshops as an exercise for reflecting on past cleaning experiences. They could thereby fulfil a supplementary role to the CUTA method in the design toolbox.

Through its combined components, the design toolbox for responsible cleaning robotisation overall offered apparent suitable benefits for facilitating collaborative and value-based design workshops involving cleaning industry participants. The methods and materials of the toolbox successfully revealed values that participants deem important in cleaning work, and explored the meanings and interpretations of those values. Certain values appeared to be in line with the findings of previous workshops, as conducted in chapter 3 of this thesis, as well relating to the overarching wellbeing needs proposed by SDT (Deci & Ryan, 2012). These values should hence be incorporated into the responsible design of future cleaning robotisation. Most of the materials were moreover effective at actively involving stakeholders in the design process, although certain components such as the hierarchy roles and scenario cards should be further developed to be more accessible. The effectiveness of the proposed toolbox based on the evaluation appears to be particularly in regards to inducing reflection by participants, to consider their current experiences and the relevant values therein, as well as their desires for improvement of cleaning work in future. On the other hand, the toolbox appears to currently be too limited for the purposes of generating new and concrete cleaning robot concepts. This fulfilment of collaborative concept generation would be required for the second phase of the approach for value-based design of Smits et al. (2019). The methods and materials proposed for this purpose, namely the robot puzzle and scenario cards, did not successfully result in robot concepts of suitable fidelity for in-depth reflection and further development. Future improvements upon the overall toolbox could therefore consider adding and testing new methods that are more effective for collaborative concept generation with industry stakeholders. The focus therein should specifically be on exploring the complexities and interactions between different features within a cleaning robot, to reach a higher level of fidelity and detail in robot concepts, compared to the results generated by the existing methods of the robot puzzle and scenario cards.

## 6.4. Conclusions

This chapter has evaluated the design toolbox for responsible cleaning robotisation, which was developed in the previous chapter 5 of this thesis. The toolbox was evaluated in two workshop sessions. The first session was conducted with product design students, and acted as a pilot for the overall usability of the individual methods and materials in the toolbox. The second and main workshop session was conducted with experienced cleaning workers, and applied the toolbox's methods and materials to engage those participants in a value-centred and participatory design process for robotisation.

The pilot workshop showed that the toolbox components were largely usable and understandable, but could benefit from adjustments in explanation and presentation. The results of the pilot did lead to the removal of the hierarchy roles narratives from the main session, as well as the choice to use the physical rather than digital iteration of the robot puzzle materials. In the main session with cleaning workers, it was shown that the toolbox is effective at facilitating discussion about participants' cleaning experiences and vision, as well as revealing and specifying important values at stake for them in robotisation of their work. The participants' responses indicate that for example the independence and autonomy of cleaning workers must be strengthened, their social engagement and interactions must be preserved, and their personal growth and ambitions must be facilitated.

On the other hand, the toolbox currently appears to be too limited for the purposes of concept generation through participatory design, though the robot puzzle and scenario cards have shown first steps in this regard that can be expanded upon. Based on the results of the workshop sessions, recommendations have been made for further development of and additions to the toolbox. These could include adding new activities, creating additional scenarios and concepts, and redeveloping existing methods to be more effective.

# 7. Discussion

The research presented in this thesis has studied the impact of robotisation on professional cleaning work, through the framework of sociotechnical values and self-determination theory. The topics of cleaning robotisation and its desired impact were investigated from three perspectives: theory and previous studies were reviewed on professional cleaning work and the impact of labour robotisation on workers; a workshop was conducted to explore the practical experiences and concerns of industry stakeholders; and the organisational transitions and barriers were modelled for robotisation within the industry. The results from these perspectives were incorporated into a toolbox of methods and materials for value-based and participatory design of future cleaning robots, which were evaluated with designers and cleaning workers.

The following will first discuss the values revealed by the results for the cleaning industry. The applicability of our results and the design toolbox for other industries and innovations will also be explored. The concepts of value-based design and the framework of SDT will be reviewed. Finally, the recommended next steps and future developments will be outlined, with regards to both the short-term and more long-term future.

## 7.1. Values for responsible cleaning robotisation

Regarding the Dutch professional cleaning industry, our results have raised concerns that will need to be accounted for as robotisation progresses. It was argued that robotisation will require a responsible design approach, which incorporates the input and values of stakeholders, particularly those of the cleaning workers that will work alongside future robots. These values must be actively designed for to achieve robots that can act as good colleagues to cleaning workers. Our findings moreover indicate specific technical features that future cleaning robot developers should take into account, while also considering the ethical concerns raised thereby.

### Key findings of stakeholder values

Participants in the workshops expressed a preference for robotisation to reduce the physical and mental workload placed on cleaning workers. Current cleaning robot products appear to already have this aim as a main focus. This is also in line with the existing public expectations for future robots, as described in chapter 2. However, participants furthermore emphasised the importance of social engagement as part of their work, including acknowledgement and appreciation from others within the cleaning environment. Robots could take a role in this, but do not fulfil this goal in current products and implementations of the technology.

Similarly, participants valued independence and autonomy, and their ability to choose their own approach to cleaning tasks without being restricted by a robot's limitations and strict procedures. Some workers fear that robotisation could lead to them being replaced, and thus losing their employment. However, our results indicate that this scenario is unlikely. Reviewing the tasks involved in cleaning work showed that there is a wide range of both cleaning and social tasks that cleaners are asked to fulfil for clients. As it stands, robots are unable to fulfil this full variety of tasks that the work entails. Though ideas exist of future humanoid 'general-purpose robots' being created, that can autonomously and intelligently fulfil the same tasks as a human, there is doubt about the technical feasibility as well as overall efficacy of such concepts (Sammut, 2012; Sheridan, 2016; Siciliano &

Khatib, 2019). There must hence be a focus on human-robot collaboration, as human and machine will be working together as a team to achieve better results, and to make the work more pleasant for workers.

Furthermore, both the theory as well as contributions from workshop participants indicated that there are issues of stigmatisation of 'dirty' cleaning work, as well as invisibility and lack of appreciation for cleaning workers. This might threaten cleaners' perceptions of their work as meaningful. Depending on their implementation, cleaning robotics can exacerbate these problems, but they can also enable improvements. For example, there is a risk that robotisation can lead to cleaning workers being perceived as doing work that could be done by machines, thereby causing objectification (Terskova & Agadullina, 2019). Conversely, robotisation could also lead to cleaning workers being perceived as operators of an advanced technology, and achieving more effective cleaning results by working with the robot (Smids et al., 2020). In the latter scenario, the social perception of the workers would be improved, as well as their own perception of their work being meaningful.

## Robots as colleagues

A concept that emerged in both preceding literature in chapter 2, as well as the contributions of industry stakeholders in chapter 3, is the notion of robots becoming colleagues. Due to the high focus on humans and robots needing to collaborate to fulfil cleaning tasks effectively, there is potential for the robots to become akin to collegial agents to workers rather than mere tools. To this end, they would need to meet the requirements and expectations of colleagues (Nyholm & Smids, 2020; Strohkorb et al., 2016). Moreover, due to the aforementioned fear of human cleaners being fully replaced with robots, industry stakeholders described that robots should not be designed as competitors to humans. That is to say, robots should aid and support humans, rather than being used to replace them.

Providing cleaners with good colleagues through robots can support their social engagement (cf. De Graaf, 2016; Smids et al., 2020), as well as offer them a sense of empowerment as they take leadership and control over the robots. They will experience more variation and choice in shaping their work, thereby enhancing their autonomy. The collaboration with a robot colleague will in this regard likely differ substantially from collaboration with a human colleague, since the cleaner will be 'in charge' of the robot and giving it instructions from a more dominant and supervising position than with a human peer. The trend may hence be towards the 'assistant' role depicted in the hierarchy narratives of the toolbox in chapter 5. This position would still notably correspond with the 'robot as (subordinate) colleague' metaphor, since it will remain a collegial agent rather than a simple tool. Finally, as mentioned above, the collaboration with an advanced technology like a robot colleague can improve the public perception of cleaning workers, thereby reducing the negative impacts of current dirty work stigmatisation. The concept of the good robot colleague can hence play an important role for improving the overall work experience of human cleaners.

With this in mind, the premise of future cleaning robots becoming colleagues to cleaning workers, as opposed to either competitors or mere tools, was included in the materials of the design toolbox. The hierarchy narratives specifically explored possible roles for the robot, ranging from a tool to a supervisor. Similarly, the scenarios and provotype concepts, particularly those optimising autonomy and competence, depicted robots with collegial qualities, namely being collaborative, trustworthy, and supportive (cf. Nyholm & Smids, 2020).

It bears mentioning that by depicting and discussing robots in this way, the materials themselves play a role in steering the narratives and interpretations of future robots, similarly to the robot marketing materials discussed by Payr (2019), as described in chapter 2. That is to say, by presenting scenarios and concepts of future cleaning robots in the role of colleague during workshops with industry stakeholders, it becomes more likely that those participants will in the future interpret cleaning robots in general as potential colleagues. Moreover, the perception of robots as colleagues and social agents could change over time, for example when humans get used to the robot being there, as hypothesised by Fink et al. (2013). The role and impact of the robot will thus be subject to value dynamism, as its perception and related values will change as robotisation progresses (Kudina, 2019). It will hence be important to continuously monitor the role of the robots and how they are used, to evaluate whether they still contribute optimally to a positive working experience for cleaners.

## Responsible cleaning robot design

To be good colleagues for cleaning work, robots will need to align with the values of stakeholders described above. These have been summarised in figure 7.1. Overall, these aspects of the human-robot collaboration represent the goals that cleaning robot developers should design for. They will need to design robots that address not only the workload placed on human cleaners, but also takes into consideration factors of social interaction, stigmatisation, and collegiality. In other words, they need a value-centred design approach to create responsible future cleaning robots.

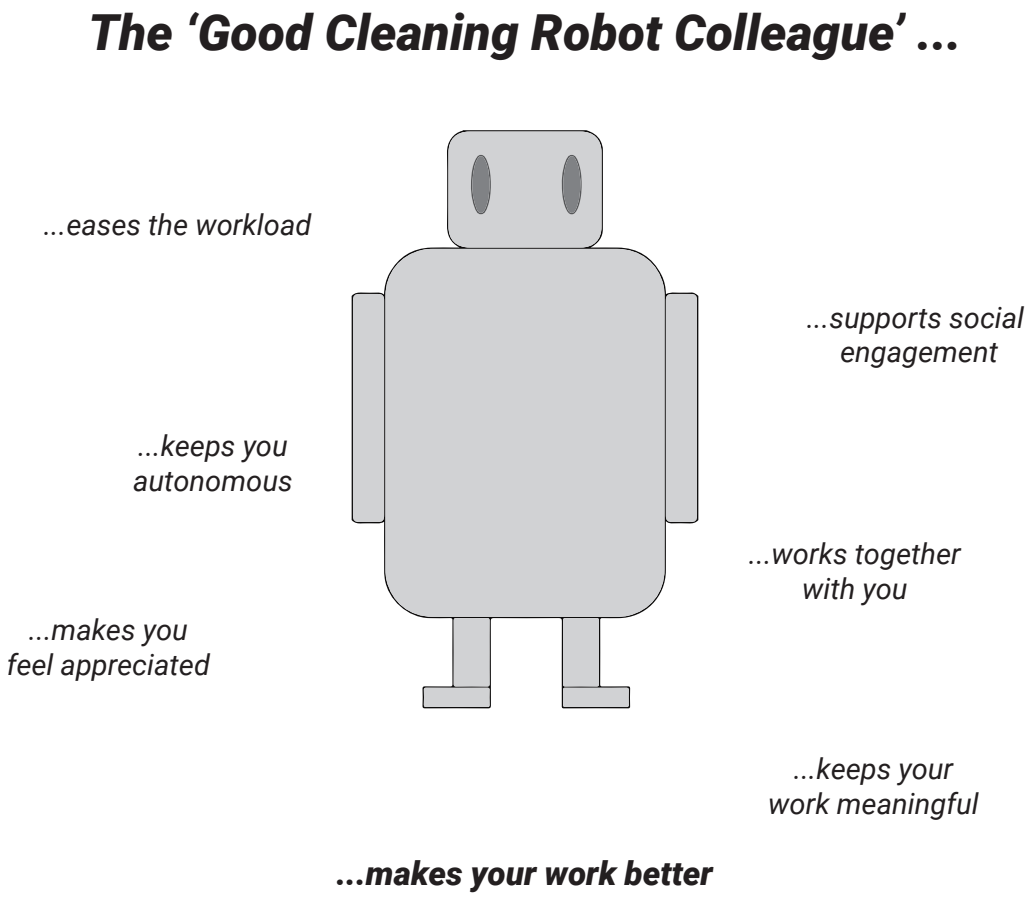


fig. 7.1. The 'good cleaning robot colleague'

The results of our literature review in chapter 2 showed that when integrating these values, designers should consider the influence of a robot's appearance (Hinds et al., 2004), social cues (Terzioğlu et al., 2020), and forms of communication (Dautenhahn et al., 2005). These will impact whether a robot is successfully accepted as a good colleague by cleaning workers. The robots will need to moreover be integrated into the organisational practices (cf. Mutlu & Forlizzi, 2008) and structures of the cleaning industry, as was shown through the framework of enterprise architecture.

## Technological developments

As was described in chapter 4, there are specific technological components relevant for the cleaning robot design process. To meet the desired level for autonomy expressed by cleaning workers in the workshops in chapter 6, the robots must be able to navigate their environment with little intervention. To achieve this, they will require suitable and effective sensors, such as the sonar and LiDAR systems that are being used in existing cleaning robot products such as for example the Diversey Swingobot (Diversey, 2021). These sensors allow a robot to observe its environment to detect obstacles as well as humans, and to then generate and continuously adapt its navigation route. To this end, the robots must furthermore be endowed with efficient and effective algorithms to process the data from the sensors and subsequently create the workflow.

The industry reports discussed in chapter 2 indicate that the industry is also considering the implementation of environmental sensors connected through IoT (FEP, 2019; Hago, 2020). These would include sensors that for example measure how much soap is used in bathrooms and inform cleaners to refill dispensers, or ones that detect how frequently specific rooms are used and hence when they will require cleaning. The industry has thus far only implemented these types of sensors in small-scale pilot-projects.

Finally, the robots could be endowed with capabilities for reporting on their cleaning performance to supervisors and management, using the data they gather. They can report on factors such as how fast they are fulfilling their tasks, how efficient they are in their water usage, and how well they manage to navigate the surrounding area. These types of features are for example currently being used in the TASKI Duobot 1850 (TASKI, 2017) and ICE's Emma robot (ICE, 2022b), described in chapter 2. Besides reporting on their own performance, the robots could also monitor the activities of human cleaners, by for example communicating to managers about instructions given by the cleaner or about how efficiently cleaning assignments were completed.

The data generated and processed through these technologies do raise ethical concerns. Participants of the initial stakeholder workshop in chapter 3 expressed a worry that the implementation of sensors, both in the environment and the robots, can compromise privacy and induce a (negative) feeling of being under constant surveillance. The sensors will be gathering information about the lay-out of the environment, as well as the movements of humans. In the case of the environmental IoT sensors described above, there is even data gathered specifically about human behaviour, as they track the use of specific facilities. Mapping people's environment, movements, and behaviour in this way can be considered fairly personal and sensitive data, and must hence be handled responsibly. The explicit or implicit gathering of data about the performance and efficiency of the human cleaning workers can similarly be considered invasive of their personal work practices. Infringements upon people's privacy in these ways can limit their sense of autonomy, as they feel less free to work the way they want. However, these privacy concerns do not appear to currently be a primary design consideration for robotics manufacturers (Chatzimichali et al., 2021). Designers are hence advised to take these more explicitly into account to ensure more responsible future robots.

### Scalability of results

These results have shown valuable insights about the professional cleaning industry, including the values, themes, and technical features that cleaning robot developers must design for. However, it must be acknowledged that the scale of this research does impose limitations to our findings, and the generalisability of described values across the entire industry. The participant groups that were consulted as part of the empirical workshop in chapter 3, and the evaluation workshops in chapter 6, were limited in size. As such, the results of these workshops may not represent the full Dutch professional cleaning industry in regards to vision and values to account for in robotisation.

Moreover, the main evaluation workshop in chapter 6 purely focussed on cleaning workers as participants, rather than including other types of stakeholders such as employers or clients. Since they are the primary end-users of future cleaning robots, these cleaning workers can be considered to be the most important stakeholders whose values and concerns must be accounted for. Having only cleaning workers participate in the workshop session moreover allowed those participants to speak more freely, since they were surrounded by peers, rather than feeling hesitant to voice concerns due to the presence of their employers.

That said, the inclusion of other types of stakeholders in new workshops could reveal additional values at stake in robotisation, as well as generate new types of concepts for future robot products. We hence recommend that future research on the topic cleaning robotisation incorporates additional workshops, which include additional cleaning workers as well as other industry participants. These additional workshops should firstly ensure the tools are accessible, understandable, and effective for all stakeholders. Secondly, they can reveal new values and themes that must be accounted for in the design of future cleaning robots, which have not yet been explored by the participants that have been included in the workshops conducted in this thesis.

## 7.2. Applicability for other domains

The research in this thesis was conducted with a specific focus on professional cleaning work robotisation, and the development of methods and materials based on that particular occupational context. Nonetheless, the theory developed, as well as the tools created, can serve as a foundation for application in other domains and occupational industries, as well reflection on other innovations.

### Robotisation in other industries

Various industries and occupations are currently undergoing robotisation shifts similar to cleaning industry. These include for example manufacturing and healthcare (Iroju, Ojerinde, & Ikono, 2017; Matheson, Minto, Zampieri, Faccio, & Rosati, 2019; Weiss et al., 2021). These industries will face challenges and questions similar to those of the cleaning industry as described in this thesis, and could hence benefit from the insights gathered.

For example, when robots are introduced into those industries, the collaboration between human and robot workers must be designed responsibly, to ensure the workers still feel satisfied in their work and perceive their contributions as meaningful (cf. Bhargava et al., 2021; Smids et al., 2020). There may also be concerns about the robots needing to be good colleagues, similar to the themes discussed in this thesis for cleaning robotisation, if this is appropriate for the particular industry and working environment (Nyholm & Smids, 2020). The ‘robot as colleague’ metaphor may take different shapes across industries.

That is, what is defined as a good colleague and the extent to which work is inherently social influence how the findings also apply to other industries.

Due to its focus on efficient output, it may for example be impractical for manufacturing workplaces to implement robots as autonomous agents and colleagues rather than as advanced tools. The metaphor of robots as colleagues would in that case be inappropriate. Conversely, since healthcare work often includes a high focus on social interactions, robots in healthcare may be expected to incorporate additional social features, such as being able to speak. They would hence need to be akin to colleagues to human workers. This was also explored in the study by Mutlu and Forlizzi (2008) of a robot's integration into the organisation and social dynamics of a healthcare environment. They found that the healthcare robots needed to be integrated into social relationships and interactions between workers, by for example delivering recorded messages. They furthermore emphasised the importance of robots not disturbing the time-critical tasks of humans, which would align with the requirements by Nyholm and Smids (2020) that a good (robot) colleague should be respectful and supportive.

It must be revealed what is at stake in day-to-day work in these industries, as well as the impact that robotisation could have on them. Responsibly addressing those impacts will require robot developers to take a value-based approach to their design. They will need to involve the stakeholders of those industries, particularly the workers, in that design process, to ensure that a responsible and effective implementation of labour robots is created. To this end, they can specifically use the toolbox designed in this research.

This will require adapting the materials, including the CUTA task cards, usage scenarios, provotypes, hierarchy narratives, robot puzzle, and scenario cards for these industries and occupations. Specifically, the context that is described for these materials must be changed from cleaning work to the respective work context that is being studied. Ideally, this should be preceded by preliminary stakeholder involvement sessions, where participants from the respective industries can describe their vision for future work, as well as the common challenges they face. Such sessions could be structured similar to the initial empirical session applied in our research, as described in chapter 3 of this thesis. The results of these sessions will then serve as input to develop materials that trigger discussion about the specific challenges and values that people face in their own work. The resulting adapted toolbox could then be used to conduct the required value-based participatory workshops to engage stakeholders in the robotisation process.

## Occupational innovations

The developed methods and materials could in addition be used to study the needs and values of stakeholders and end-users for occupational innovation processes besides robotisation, such as automation, virtual agents, and digitalisation. These technologies could be explored for their viability and impact in the professional cleaning industry, or for other industries such as those described in the above section. As methods, the CUTA task cards, usage scenarios, provotypes, and scenario cards could be directly adapted for these technologies. New workshop materials would need to be created for these methods, which depict the chosen technology and its impact on the work experience. For example, new usage scenarios for digitalisation could depict how workers engage with variants of digital platforms that enable them to track their work tasks, and how those platforms affect their work enjoyment.

The hierarchy narratives and robot puzzle would likely require more significant changes to be applicable for other innovations, since they were originally created for robotisation specifically. They explore the specific topics of respectively robots acting as social

and hierarchical agents, and the notion of multi-functional robots with a variety of task capabilities. These methods would need to be replaced with new ones, suited for the alternative technologies. For example, a new toolbox could include an activity wherein participants can assign personality traits to a virtual agent.

Usage of a new toolbox in this way could empower stakeholders and end-users of new innovations in cleaning and other occupations to take part in the innovation process, shape new technologies to their needs and visions, and to preserve their values. Besides the industries described previously in this section, this could be of interest for occupations that have other characteristics similar to cleaning work, such as reliance on physically intensive and repetitive labour, and a stigmatised societal perception as dirty work. Such industries include for example garbage disposal and mining (Ashforth & Kreiner, 1999; Hamilton et al., 2019). These industries can be expected to also value social engagement, workload reduction, and visibility and appreciation, similar to the value-findings for cleaning work resulting from the research in this thesis. Conversely, there will likely be important differences in the values held by workers in those industries. Garbage disposal workers may emphasise more the importance of self-reliance and resilience (Hamilton et al., 2019). Mining workers could face more significant issues of dignity and a need for a strong work identity due to the high degree of physical taint involved in their work (Ashforth & Kreiner, 1999).

## 7.3. Value-based design

The research in this thesis has taken a value-based approach to study the impact of robotisation on cleaning work and the day-to-day work experience of cleaning workers. Through theory, empirical workshops, and organisational modelling, values were revealed that are relevant and at stake as the professional cleaning industry implements robotisation. Workshop methods and materials were then developed to reveal further values of stakeholders, as well as facilitate the deeper exploration of the meaning and interpretation that stakeholders ascribe to such values. Through evaluation sessions, wherein the toolbox contents were applied in workshops with designers and cleaning workers, the tools' effectiveness for value-based design was assessed. It was determined that the tools successfully facilitated participants' discussions about cleaning work and their future vision and needs, and particularly revealed and specified the values they deemed important and at stake in cleaning robotisation. However, it was also found that the methods and materials are still limited for the purpose of full collaborative concept generation, which is the second phase of the framework of Smits et al. (2019). The toolbox would hence require further development to fulfil this particular part of the collaborative design process.

More broadly, the application of this type of value-based approach enables us to reflect on its viability as a framework for studying and discussing the development of new innovations, such as cleaning robots. As discussed previously, value-based design approaches face various challenges to be successfully and effectively applied. Interpretations of values will differ between stakeholders. This means that the same overarching values will have a different meaning for different stakeholder groups. An example was previously described in chapter 4, as clients and employers in cleaning industry consider efficiency from the perspective of financial resources required to fulfil cleaning tasks, whereas workers will largely interpret efficiency as describing physical effort required for those tasks. The toolbox designed in this thesis can notably aid in facing this challenge of differing value interpretations, as it was shown to facilitate stakeholders to describe their specific

experiences and beliefs. Another challenge for value-based approaches is to identify all stakeholders involved in an innovation process. Once identified, it can still be difficult to practically involve all those stakeholders in the process. This can hence limit the viability of value-based approaches. The toolbox designed in this research can in part address this challenge, by making the discussions about values and the wishes for robotisation accessible to participants from varying backgrounds and positions within the industry.

Aside from these previously discussed challenges, the results of the research in this thesis however revealed an additional issue for value-based stakeholder involvement that must be explored. Namely, there appears to be a discrepancy between the way researchers and ethicists consider values and dilemmas, compared to the way stakeholders consider the issues they face (cf. Manders-Huits, 2011). In our studies, it was at times difficult to convey the concept of 'values' to participating stakeholders, as it appeared they did not consider their personal experiences to involve concepts such as for example freedom, satisfaction, or wellbeing, or that a technology such as robots might impact them on such a level. At the same time, when those participants went on to describe their practical experiences, as well as their vision and wishes for future work, it was possible to discern sociotechnical values in those descriptions, even if those participants did not ascribe such terms to them.

For example, when asked directly, interviewed cleaning workers found it difficult to imagine how a robot could affect their freedom. However, when they were asked during the workshop with the toolbox to explore their desired characteristics for a cleaning robot based on the provotype concepts, participants described how they wanted a robot that can work independently to allow themselves to also work on their own with their own approach. In the evaluation of the workshop's results, these responses were related to desired personal freedom and independence, even if the participants never explicitly mentioned such terms.

Overall then, the gap between the ethical focus on the level of values, and the practical stakeholders' perceptions based on specific examples and anecdotes, must be bridged. This gap can prove a challenge for the practical application of a value-based approach for stakeholder involvement. It can require researchers to do a greater degree of interpretation in order to relate stakeholders' input to sociotechnical values. It moreover introduces a risk for misinterpretation, when researchers potentially misattribute overarching values to the responses of stakeholders. This could subsequently steer the design process incorrectly, if it leads to designers focussing on different values from those most important to the stakeholders. To prevent this, and bridge the gap, stakeholders should be engaged in terms and concepts that are familiar and accessible to them. This can for example involve the aforementioned specific examples and anecdotes. Researchers should then attempt to reveal, through for example interviews or ethnography, the underlying motivations and beliefs behind the practical experiences of the stakeholders, because these represent the sociotechnical values (cf. Van de Poel & Royakkers, 2011).

The tools proposed for the design toolbox for responsible cleaning robotisation do appear to achieve this goal, by providing participants with concrete examples and questions to discuss. When they were applied in the evaluation workshops, the tools prompted participants to share their experiences and wishes for future robots. Through follow-up questions as part of the sessions, the researchers were able to discern the values that motivated those contributions. Other tools can be created, both for the specific case of professional cleaning robotisation as well as other contexts, that fulfil a similar role of sparking discussion by participating stakeholders about their concerns, based on their preferred terms and theoretical concepts. These could include for example new scenarios

and design fictions, or roleplaying exercises using props and prototypes, which enable participants to express their desired working experience. These should then be followed by structured interviews to distil those visions and ideas to values.

## 7.4. Self-determination theory

In this research, SDT was specifically brought in as an additional framework for considering the cleaning industry and cleaning robotisation. The results and analysis of the workshop in chapter 3 of this thesis indicated that the framework of SDT offers a suitable core of basic needs for cleaning workers' wellbeing, consisting of autonomy, competence, and relatedness. These can be connected to many more specific sociotechnical values that are at stake within cleaning work. To be a good colleague, a future cleaning robot must support a cleaner's wellbeing through the three core needs of SDT. Doing so will furthermore ensure the cleaner's work is meaningful (Smids et al., 2020).

There were however also values and themes relevant for the case of cleaning robotisation that could not be covered by SDT as an overarching framework. These include elements such as privacy and enjoyable employment. Since these elements were described as important by participants in workshops throughout this research, they must still be taken into account as part of the value-based and responsible design of future cleaning robots. This may require including them either separately, or through the use of additional theoretical frameworks. In the toolbox, the CUTA task cards were for example used to explore which tasks contributed to enjoyable employment.

Despite not offering full coverage of all potential values, the framework of SDT was found to be an effective starting point for exploring the core needs of cleaning workers. As such, it acted as the basis for certain tools within the developed design toolbox. Each of the usage scenarios that were created specifically describes a robot's effects on one of SDT's basic needs. The scenarios also address the aforementioned gap in understanding and perspective between ethical theory and stakeholders' practical experiences. Each scenario specifically describes through example what the needs of autonomy, competence, and relatedness mean, and how and why they are affected by the described robots. This made the concepts of values more accessible and understandable for participants. SDT's basic needs moreover acted as the core inspiration for the provotype concept mock-ups, with each concept focusing on the optimisation of one of the needs.

The use of SDT in this way within the toolbox acted as a basis for exploring the implications of the scenarios and the preferences and wishes of participants with regards to what a future cleaning robot should prioritise and be capable of. It allowed participants to discuss their interpretations for what autonomy, competence, and relatedness mean in their daily work, and hence how those core wellbeing needs can be better fulfilled in the future. By giving meaning to the wellbeing needs in this way, designers of cleaning robots will have a better understanding of how to adequately improve the experience of cleaning work.

If, as suggested earlier in this chapter, the design toolbox for responsible cleaning robotisation is adapted for use in other occupational contexts, it will need to be considered how SDT fits into those respective industries. Across industries and occupations, workers might prioritise the SDT needs differently. Workers in manufacturing may for example find it most important to feel autonomous in their work, whereas the workers in cleaning placed particular importance on relatedness through a sense of community with colleagues. Moreover, the interpretation and meaning that workers from different occupation ascribe to each of SDT's needs will differ. Each worker defines their values and their wellbeing needs through their personal beliefs and practical experiences. For example, whereas

a worker in cleaning would consider competence to be about how fast they can clean a particular space, a healthcare worker may define their competence as making a patient feel as healthy as possible. These differences in priority and interpretation of the three basic needs of SDT must be considered when adapting the results of this research as well as the toolbox to new industries. For new materials, scenarios should be written that understandably convey the concepts of autonomy, competence, and relatedness to participants in ways they can recognise from their own experiences. Similarly, provotypes concepts should be designed that optimise the core needs in ways that affect the actual interpretations and meaning that stakeholders have for those needs. This will ensure that the tools can be effective for those purposes.

## 7.5. Future vision

Based on the results of the research, the recommended next steps and trends for cleaning robot development can be determined. These constitute short-term recommendations for implementation of the design toolbox, as well as the specific values that robot developers must design for. Furthermore, a longer-term vision can be formulated for how cleaning robotisation could and should develop further in the future to achieve the ideal robot colleagues for cleaning workers.

### Short-term

In the short-term, developers of new cleaning robots should aim to not only focus on workload reduction through cleaning task automation, but also consider wider impacts of their design on the experience of cleaning work and the values at stake therein. The work satisfaction of cleaners should be improved, by building robots that can act like good colleagues. To be supportive colleagues, these robots should take over those tasks that are most unenjoyable, such as the touch surface cleaning and bathroom cleaning tasks that were described by participants in the workshop in chapter 6. Moreover, it will be important to consider the impact a new robot will have on users' sense of independence and autonomy, as they are being trained to work with this new kind of technology, and the social engagement they have with other people. Robots should be designed to support these values, by enabling the workers to approach their tasks in the way they choose, and by leaving space for and even facilitating interactions between cleaners and other occupants of the building.

Addressing these and other issues will require the robot designers to take the value-based participatory approach that has been the focus of this thesis. They can for this purpose make use of tools and materials such as those that have been created in this research for the design toolbox for responsible cleaning robotisation. These tools should hence be incorporated into the design practices of cleaning robot manufacturers. They can moreover be used by cleaning organisations as well as organisations such as RAS, to explore and define the wishes and requirements for new cleaning robots to be developed, and how they would like robotisation to enhance the work of cleaners. These wishes and requirements can then act as instructions for new cleaning robots to be commissioned. This value-based approach will also continue to be used in the partner EngD research project, which aims at the conceptualisation and prototyping of a full cleaning robot product. Said project will iterate upon the data gathered in this thesis, to develop a design that specifically addresses the sociotechnical values at stake, and to thereby actively and immediately contribute to a better future of cleaning work if the resulting robot product is brought to market.

### Long-term

Long-term, extrapolating and speculating on current trends would indicate that in the future an increasing number of cleaning tasks will be taken over from human cleaners and performed by robots instead. Though concepts have been proposed for multifunctional robots that incorporate multiple cleaning functions into a single robot (Bormann et al., 2015), it is likely that this will for practicality consist of multiple robots being placed into the same cleaning environment, each with their own specialised functions (Kopacek, 2017; Sheridan, 2016). The collective group of robots will then be overseen by one or more human cleaners acting as operators. These operators will likely still need to fulfil certain cleaning tasks, that are either too complex or too financially inefficient to be automated through robotisation. Such tasks would include for example the strategic planning of cleaning tasks, choosing a plan of approach for cleaning the assigned space and subsequently giving suitable instructions to a cleaning robot. These types of tasks additionally offer the cleaners empowerment and control, as they are enabled to autonomously decide how they wish to work and what tasks their robot colleague should be doing. Beyond this supervision role, as robots take over tasks from humans, the cleaners will likely also need to adopt new tasks. Examples of new potential future tasks for cleaners include maintenance and custodial duties, acting as a host for the building, or the training of new cleaners. Which type of tasks would be most suitable will depend on the specific cleaners, and for the sake of their independence and autonomy, it is advised to consult them on how their work should be reshaped in the future.

More broadly, the desired future vision for cleaning work and robotisation is for robots to enhance the satisfaction and wellbeing of human cleaning workers. This can be achieved in part by addressing their needs for autonomy, competence, and relatedness, as suggested by SDT (Deci & Ryan, 2012; Ryan, 2009). For addressing these specific needs for wellbeing, the scenarios developed as part of the toolbox in chapter 5 of this thesis can act as guidelines to work towards, as each describes how a robot can improve on the respective aspects. Long-term robot developments must moreover address those values which are not covered by SDT's overarching wellbeing needs, such as safety, privacy, and pleasure, as indicated in chapter 3. Future robots should be future colleagues, with a focus on collaboration, and ensure that cleaners' jobs offer pleasure and respect, in a manner that is sustainable to the workers' long-term health. As the technologies of cleaning robots advance, so too must the working experience of human cleaners. Robots will thereby contribute to a better professional cleaning industry for the future.

## 7.6. Closing remarks

This thesis opened with the conclusions of a review of the market of cleaning robotics by Schofield (1999). She concluded that at the time there was technological viability for an autonomous cleaning robot to be created, but that there was a lack of knowledge regarding the human context, and the new working practices and social dynamics required. Responsible cleaning robots must be developed that support the needs and wishes of workers, and make their work better as a result, as a good colleague would do. Through the research in this thesis, we have built a framework of knowledge and created tools that robot designers can use to address the human context and the values at stake in robotisation of cleaning. With these tools in hand, we can give cleaners the colleague they deserve.

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# Appendix

# Appendix A: Cleaning Robot Use Scenarios

## Mark (English)

Mark has worked in cleaning for 11 years now, always with the same company, but with at this point many clients under his belt. His most recent appointment is with a large consultancy firm, whose head offices are in need of cleaning services. Mark has felt welcomed and appreciated since starting there three months ago, his dry sense of humour a useful asset when chatting in the hallways with the firm's younger employees.

When taking the appointment, Mark was told by his supervisor that soon after starting there, he would be getting a peculiar new colleague: a robot. This robot would take over some of the work he used to be doing, specifically the scrubbing and vacuuming of the hallways and large areas. Mark was going to be in charge of the robot himself, a new responsibility!

When the robot was brought in, Mark first needed to teach it some things about the cleaning work at the firm. He had to push the robot along its planned route, indicating along the way where to perform the individual cleaning tasks. It was quite an intensive task, but happily he only had to do it once as from then on the robot was largely able to operate on its own. It could even use inbuilt sensors to avoid sudden obstacles and even humans in its path. Mark would however still need to check in on occasion to make sure it was doing its job properly.

Ever since, Mark has been feeling a bit more relaxed at work. If he had to be honest, much as he loves his job overall, cleaning all those floors was always a somewhat annoying and draining. Now he just has to occasionally fix some corners or small areas the robot has missed in its route. And Mark can now do some easier and fun tasks.

As he's clearing one of the offices, one of the client employees passes by, and they get to chatting. The robot makes for a common conversation topic, Mark noticed, as people get curious about what it does and how it works. He gets asked whether he likes having a mechanical colleague. Mark just shrugs, and with a smile says "Well, it certainly beats having to tell every intern who comes in here how to keep the floors tidy."

Because it encourages conversation, the robot gives Mark a strengthened sense of relatedness. What this means is that he feels more like a part of the company, and he can more easily build friendly relationships with the people around him by talking to them.

# Mark (Nederlands)

Mark werkt nu al 11 jaar in de schoonmaak, altijd bij de zelfde werkgever, maar wel al met meerdere klanten achter de rug. Zijn huidige opdracht is bij een groot consultancy bedrijf, waar het hoofdkantoor moet worden schoongemaakt. Mark voelt zich er welkom en gewaardeerd sinds hij er drie maanden geleden begonnen is, zijn droge gevoel voor humor bleek nuttig om een band op te bouwen met de jongere werknemers van de organisatie.

Toen hij de opdracht kreeg werd Mark door zijn leidinggevende verteld dat hij kort na begin een speciale nieuwe collega zou krijgen: een robot. Deze robot zou een deel van het werk overnemen dat hij normaliter deed, specifiek het schrobben en stofzuigen van de gangen en grote binnenruimtes. Mark zou zelf de leiding hebben over de robot, een nieuwe verantwoordelijkheid!

Toen de robot werd geïmplementeerd moest Mark deze eerst wat dingen leren over het schoonmaken in het gebouw. Hij moest de robot langs de geplande route voor zich uit schuiven, en gedurende de route aangeven waar bepaalde schoonmaaktaken uitgevoerd moeten worden. Het was een vrij intensieve taak, maar gelukkig moest hij het slechts een keer doen omdat de robot daarna zo goed als alleen kon werken. De robot kan zelfs ingebouwde sensoren gebruiken om obstakels en zelfs mensen op het pad te vermijden. Mark moet echter wel af en toe checken dat de robot het werk goed doet.

Sindsdien voelt Mark zich net iets meer ontspannen tijdens het werk. Als hij eerlijk moet toegeven, zozeer hij van zijn werk algemeen houdt, het schoonmaken van al die vloeren was toch altijd wat vervelend en vermoeiend. Nu moet hij alleen maar af en toe de hoekjes en kleine stukjes doen die de robot heeft gemist op de route. En hij kan nu wat makkelijkere en leukere taken doen.

Terwijl hij een van de kantoorruimtes aan het opruimen is loopt een van de medewerkers van het gebouw langs, en ze raken in gesprek. Mark heeft gemerkt dat de robot een veel voorkomend gespreksonderwerp is, omdat de mensen nieuwsgierig worden wat het kan en hoe het werkt. Hij wordt gevraagd of het bevalt om een mechanische collega te hebben. Mark haalt zijn schouders op en antwoord met een glimlach, “Ach, het is hoe dan ook beter dan wanneer ik elke stagiair die hier komt moet uitleggen hoe ze de vloeren een beetje netjes houden.”

Omdat het voor meer gespreksvoer zorgt, geeft de robot Mark een sterker gevoel van verbondenheid. Wat dit betekent is dat hij zich meer deel van het bedrijf voelt, en hij kan makkelijker een vriendschap en relatie opbouwen met de mensen om hem heen door met hen te praten.

# Dunja (English)

Dunja is a professional cleaner with at this point 7 years of experience. Her official employer has changed a few times over the years, but this was mainly the result of corporate takeovers. Her main assignment nowadays is with a large producer of consumer goods. Dunja is assigned to the firm's main building, where she is in charge of cleaning both the administrative offices and the production hall, together with two colleagues. It's a good place to work, and she feels part of company. In fact, she often introduces herself as an employee of the client rather than of her employing cleaning organisation.

In an agreement between the client and her cleaning organisation, there has recently been a new addition to the equipment: a cleaning robot. The robot is fairly small, shaped like a large disc. It has a vacuum and mopping function, using a small water tank. At designated stations, the robot can refill its tank and charge itself. It can navigate narrow spaces and avoid obstacles. Dunja was asked for her advice where it would be of most use within the building, to which she suggested the office areas, since it can easily get under desks.

The robot has sensors to observe its environment, and can even detect nearby dirt and dust. It can move and navigate on its own, so from the moment it was brought in, it was ready for use. Dunja can activate the robot, as well as give it specific instructions, using an application on her company phone. She was told that the robot's navigation does run into problems occasionally, such as getting stuck near certain obstacles, which would require her intervention to resolve. If that occurs, she would be getting a message on the phone that the robot needed her help. Other than that however, she was told she could largely leave the robot on its own to work.

Having worked with it for a few weeks now, Dunja is thus far quite satisfied. It's a bit annoying whenever she gets a message that the robot got stuck somewhere, but it feels like more recently it has finally started learning to avoid certain situations that lead to problems. That means Dunja has been able to focus her attention on the production hall, which has always been the more challenging part of her job, due it needing a bit more of a creative and critical eye to get an overview of what needs to be done. But Dunja likes a challenge, so that fits her.

Because it allows her to work more freely, the robot gives Dunja a strengthened sense of autonomy. What this means is that she feels like she has more space to choose how she wants to do her tasks. She was also asked for her insight how and where the robot should be used, which gave her the chance to choose what she would like her work to look like.

# Dunja (Nederlands)

Dunja is een schoonmaker met ondertussen 7 jaar werk ervaring. Haar officiële werkgever is door de jaren heen meerdere malen veranderd, maar dit was hoofdzakelijk als gevolg van bedrijfsovernames. Haar belangrijkste opdracht is momenteel bij een grote producent van consumentenproducten. Dunja werkt in het hoofdgebouw, waar ze samen met twee collega's zowel de kantoren als de fabriekshal schoonmaakt. Het is er fijn werken, en ze voelt zich deel van het bedrijf. Sterker nog, ze stelt zich vaak aan anderen voor als werkend bij de klant dan als werknemer van haar werkgevende schoonmaak organisatie.

In overeenkomst tussen de klant en het schoonmaakbedrijf is er onlangs een nieuw soort gereedschap voor Dunja bij gekomen: een schoonmaakrobot. De robot is tamelijk klein, gevorm als een grote schijf. Er is een ingebouwde stofzuiger en een dweilfunctie, die gebruik maakt van een kleine watertank. Op speciale stations kan de robot zelf de tank vullen en de batterij opladen. Het kan kleine ruimtes navigeren en obstakels vermijden. Dunja werd gevraagd naar haar advies waar de robot het nuttigst zou zijn in het gebouw, waarop zij de suggestie gaf voor de kantoorruimtes, gezien de robot makkelijk onder de tafels kan komen.

De robot heeft sensoren om de omgeving waar te nemen, en kan zelfs stof en viezigheid in de buurt detecteren. Het kan zelf bewegen en navigeren, dus vanaf het moment dat robot werd binnengebracht was deze klaar voor gebruik. Dunja kan de robot aanzetten, en ook specifieke instructies geven, door middel van een applicatie op haar bedrijfstelefoon. Haar werd gezegd dat de robot af en toe wel problemen kan ervaren met navigatie, zoals vast komen tussen bepaalde obstakels, en in dat geval zou zij moeten ingrijpen. Mocht dat gebeuren zou zij een bericht op de telefoon krijgen dat de robot hulp nodig heeft. Verder zou zij de robot echter grotendeels alleen kunnen laten om het werk te volbrengen.

Na er een paar weken mee gewerkt te hebben is Dunja grotendeels tevreden. Het is een beetje irritant wanneer ze het bericht krijgt dat de robot weer eens ergens vast zit, maar het lijkt alsof de robot meer recentelijk begint te leren om bepaalde situaties te vermijden. Dat betekent dat Dunja nu meer heeft kunnen focussen op de fabriekshal, wat altijd het meer uitdagende deel van haar functie is geweest, omdat het meer creativiteit en een kritisch oog vereist om een overzicht te maken van wat er moet gebeuren. Maar Dunja houdt ook wel van een uitdaging.

Omdat het haar mogelijk maakt om vrij te werken, geeft de robot Dunja een sterker gevoel van autonomie. Wat dit betekent is dat zij voelt dat zij meer ruimte heeft om te kiezen hoe ze haar taken wil doen. Ze werd bovendien gevraagd naar haar ideeën voor hoe en waar de robot gebruikt zou moeten worden, wat haar de kans gaf om te beslissen over hoe haar werk eruit ziet.

# Sven (English)

Sven is a young newly trained cleaning worker three months into his employment with a large cleaning organisation. He has his first assignment with a small accountancy firm, who require cleaning of their office areas. It has been a new experience for Sven, but he luckily has an experienced colleague with him there acting as a sort of supervisor, who has taken him under his wing.

In fact, he has two colleagues working with him, although one of those colleagues is a robot. The small robot can vacuum the carpets in the office, as well as using light to let dust drop from the air to the ground. It is a handy gadget that makes Sven and his supervisor's job a bit easier and more relaxed. While the robot does its job, they can simultaneously do other tasks in the room.

The robot doing the vacuuming means one less task that needs to be done by Sven. The robot can move through the room on its own, but Sven does need to lift it across thresholds and more importantly up and down the stairs. The robot is quite bulky and heavy to lift, which worries Sven somewhat. Sven never really liked the vacuuming during his training, so he's happy he can focus more on the spot cleaning now, such as cleaning the desks and windowsills.

"Hey Sven," his supervisor says as he pokes his head in the room, "I'm finished next door, how are things looking here?" Sven looks up from the window he was working on, and responds dutifully "Yeah, almost done. Just need to do this last window. And this guy'" he says, as he points to the robot working on the floor, "should be finished with the carpet soon as well."

Because it enables him to work faster and better, the robot gives Sven a strengthened sense of competence. What this means is that he feels like he can get the rooms cleaner than before, and also faster, because he has assistance from the robot now. He moreover feels like he is picking up new skills by learning to work with a robot.

# Sven (Nederlands)

Sven is een jonge en nieuw opgeleide schoonmaker die nu drie maanden werkt bij een grote schoonmaak organisatie. Zijn eerste opdracht is bij een klein accountancy bedrijf, waar de kantoorruimtes schoongemaakt moeten worden. Het is een nieuwe ervaring voor Sven, maar gelukkig heeft hij een ervaren collega als leidinggevende bij zich, die hem helpt wanneer dat nodig is.

Sterker nog, hij heeft twee collega's die met hem werken, al is een van die collega's een robot. De kleine robot kan de tapijten in het kantoor stofzuigen, en kan ook door middel van licht de stof in de lucht naar de grond laten vallen. Het is een handige gadget die het werk van Sven en zijn leidinggevende een beetje makkelijker en meer ontspannen maakt. Terwijl de robot zijn werk doet, kunnen zij ondertussen andere taken doen in de kamer.

Omdat de robot het stofzuigen doet is er een taak minder te doen voor Sven. De robot kan zelf door de kamer bewegen, maar Sven moet hem wel over drempels, en belangrijker nog trappen, tillen. De robot is tamelijk zwaar en onhandig te tillen, waar Sven zich wel een beetje zorgen over maakt. Sven vond het stofzuigen niet echt leuk gedurende zijn training, dus hij is blij dat hij zich nu meer op plaatselijke schoonmaak kan richten, zoals de bureaus en vensterbanken.

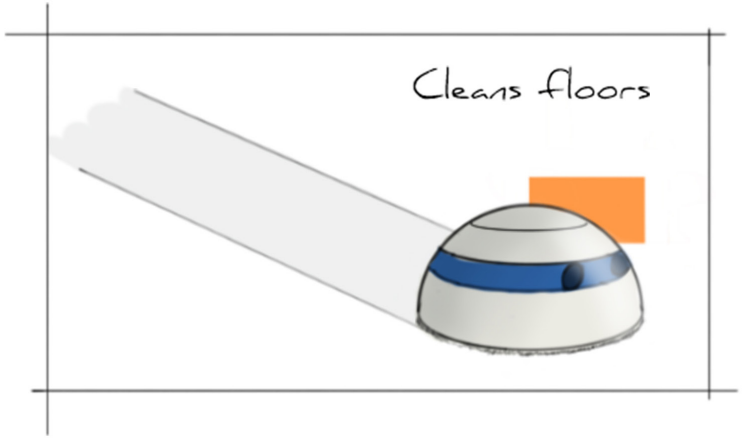
"Hey Sven," hoort hij zijn leidinggevende zeggen als deze zijn hoofd de kamer in steekt, "Ik ben klaar hiernaast, hoe ziet het er hier uit?" Sven kijkt op van het waar hij aan het werk was, en antwoord "Ja, bijna klaar. Alleen nog dit laatste raam. En hij," zegt hij, wijzend naar de robot op de vloer, "zou ook bijna klaar moeten zijn met het tapijt."

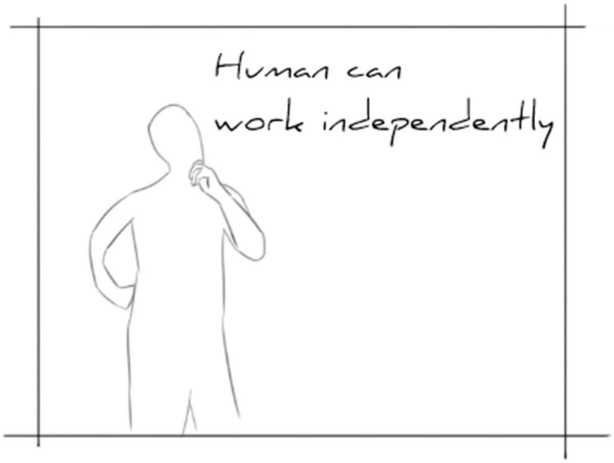
Om het hem in staat stelt om sneller en beter te werken, geeft de robot Sven een sterker gevoel van competentie. Wat dit betekent is dat hij voelt dat hij de kamers schoner krijgt dan eerder, en ook sneller, omdat hij hulp krijgt van de robot. Bovendien heeft hij het gevoel dat hij nieuwe vaardigheden aan het oppikken is door te leren werken met een robot.

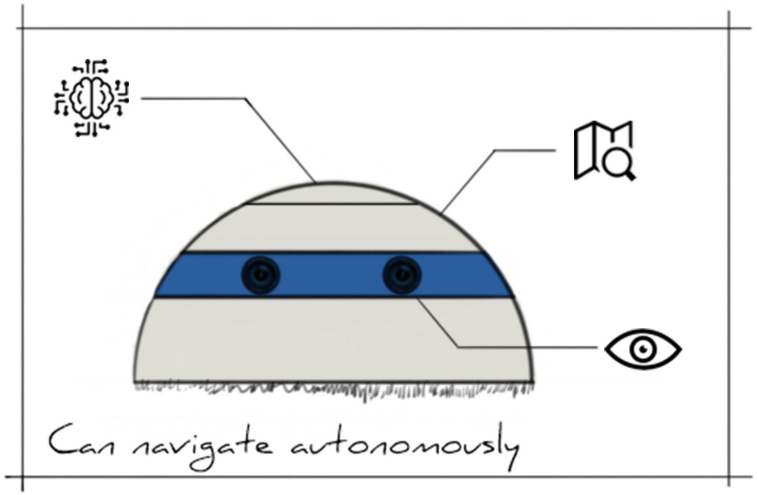
# Appendix B: Provotype Concept Mock-up Sketches

# Autonomy

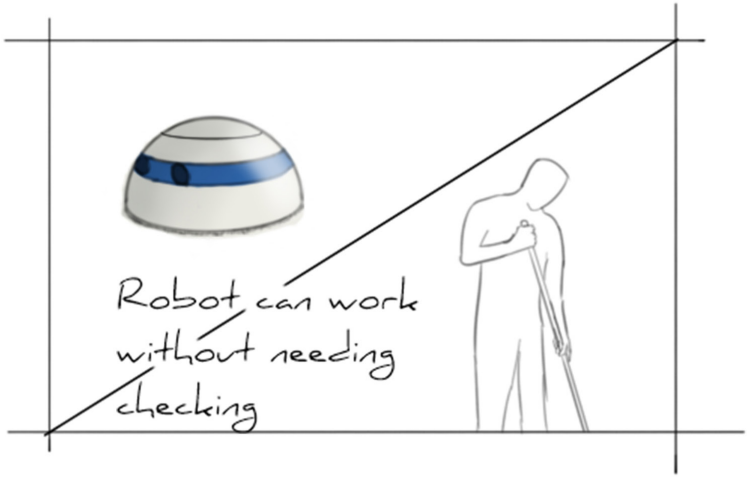
The robot is focussed on alleviating repetitive and restrictive tasks from the human, leaving the free and creative tasks that allow the human cleaner decision freedom and power, providing opportunity for job crafting.



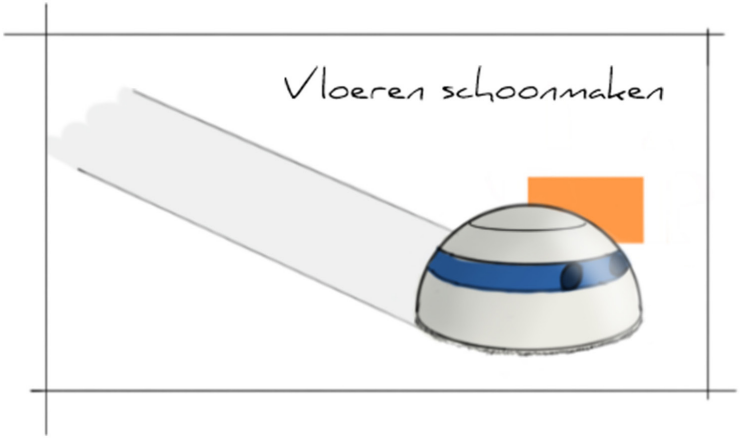




The robot takes over the floor cleaning tasks. It can work effectively and reliably, so the human cleaner does not need to continuously check in. The robot can work independently, using sensors to perceive and navigate the environment. It can make its own plans of how to clean the floors. The human can meanwhile do something that requires more freedom of choice and approach.

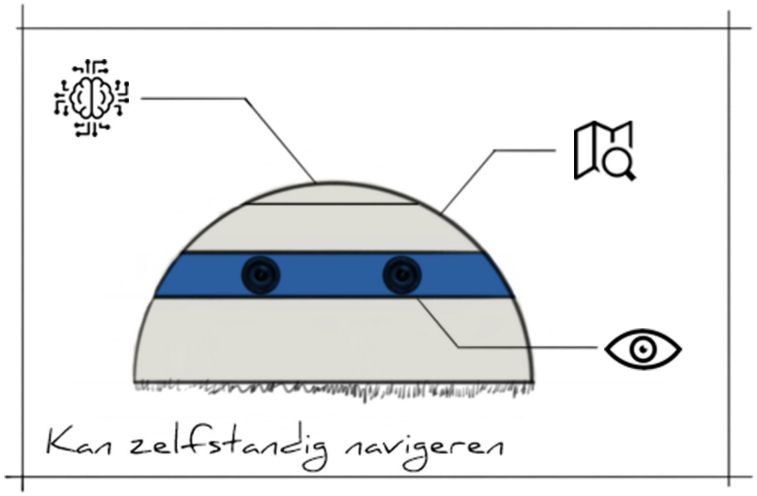


# Autonomie

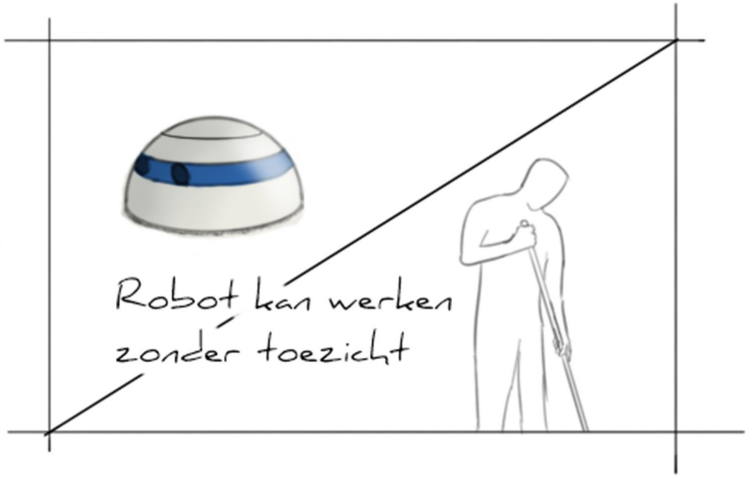
De robot is gericht op het overnemen van eentonige en beperkende taken van de mens, waardoor de vrije en creatieve taken overblijven die de menselijke schoonmaker de vrijheid en kans geven om keuzes te maken, en herinrichten van dagindeling mogelijk maakt





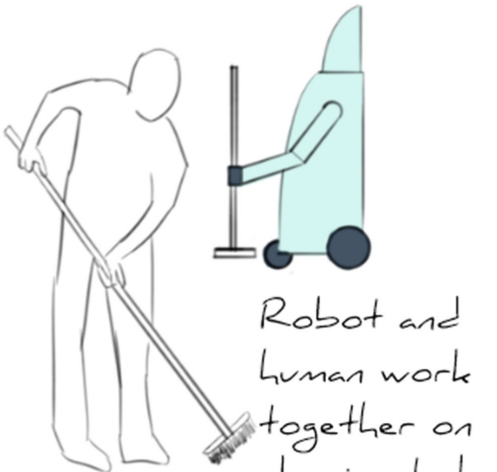



De robot neemt de taken voor vloer schoonmaak over. De robot is effectief en betrouwbaar in het werk, zodat de mens niet continu hoeft te checken hoe het gaat. De robot kan onafhankelijk werken, en maakt gebruik van sensoren om de omgeving te zien en te navigeren. De robot kan eigen plannen maken voor hoe de vloeren schoon te maken. De mens kan ondertussen iets doen met meer keuzevrijheid en vrijheid voor benadering.

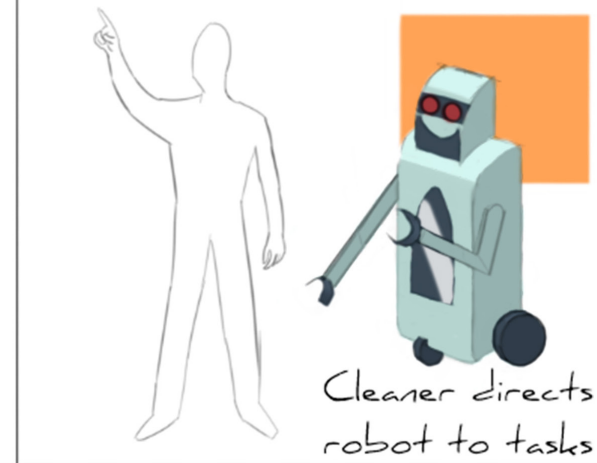


# Competence

The robot is aimed at supporting the human cleaner's skills, making them feel more empowered and capable. It works together with the human as an assistant, following the cleaner's directions for what to do.

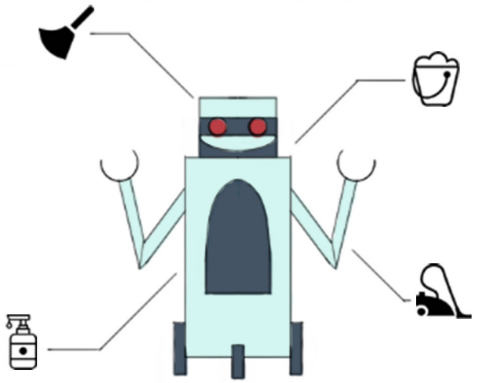


Robot and human work together on cleaning tasks



Cleaner directs robot to tasks

The loyal robot joins the human on the cleaning round, following verbal commands for areas to clean with its diverse cleaning functionalities. The human is working in the same area meanwhile, combining the strength of human and machine to complete the work.



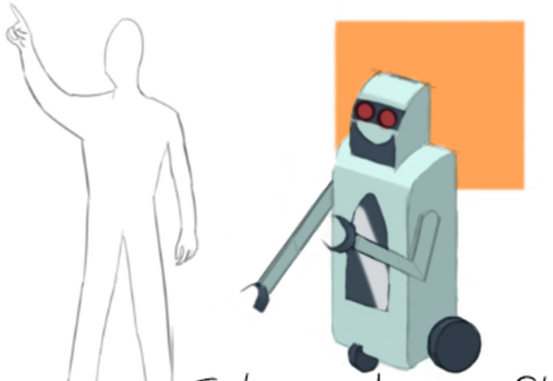
Robot can fulfil variety of cleaning tasks

Robot as a collaborator

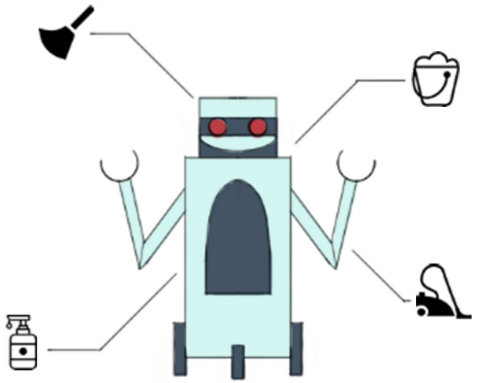
# Competentie

De robot is gericht op het ondersteunen van de vaardigheden van de menselijke schoonmaker, waardoor deze zich gesterkt en bekwaam voelt. De robot werkt samen met de mens als een assistent, en volgt de instructies van de schoonmaker op.

Robot en mens werken samen aan schoonmaak



Schoonmaker geeft robot instructies



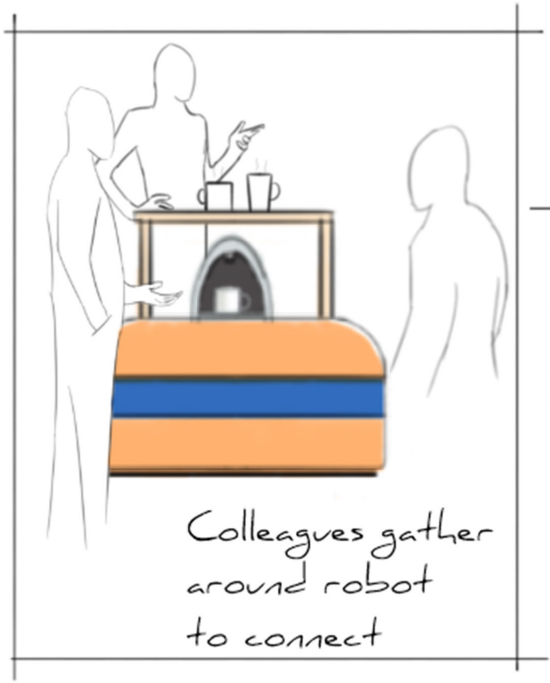
Robot kan diverse schoonmaak taken vervullen

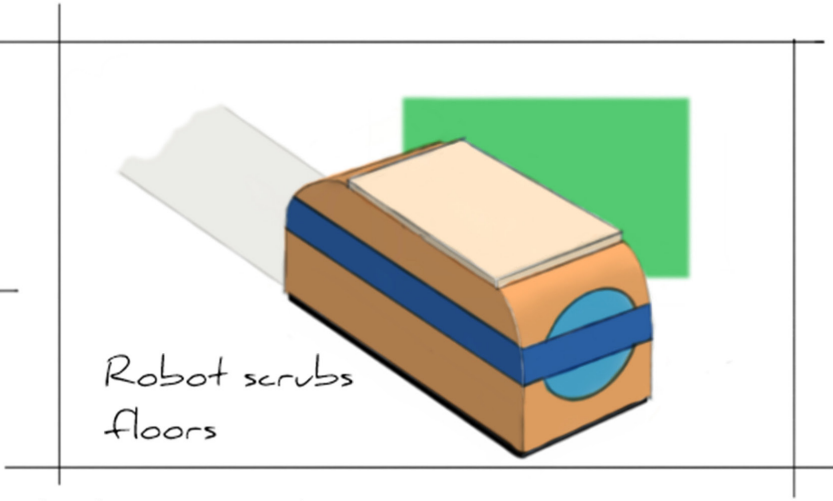
De loyale robot gaat met de mens mee voor de schoonmaak ronde, en volgt mondelinge instructies op voor ruimtes om schoon te maken met diverse schoonmaak functies. De mens werkt in dezelfde ruimtes ondertussen, om zo de kracht van mens en machine te combineren om het werk te voltooien.

Robot als een collega

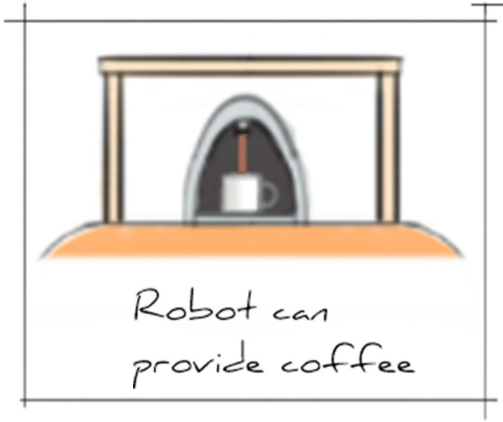
# Relatedness

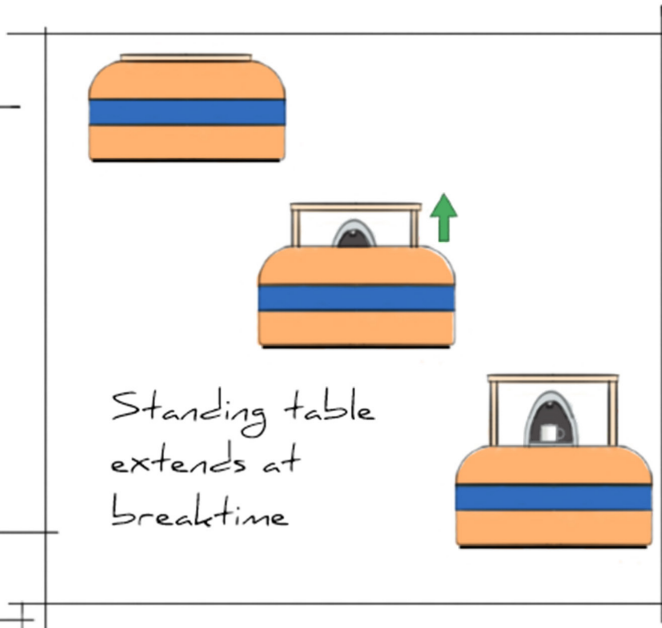
The robot is aimed at giving humans a sense of community and belonging, supporting social interactions and relationships. It brings inhabitants of the building together, serving as a social hub.

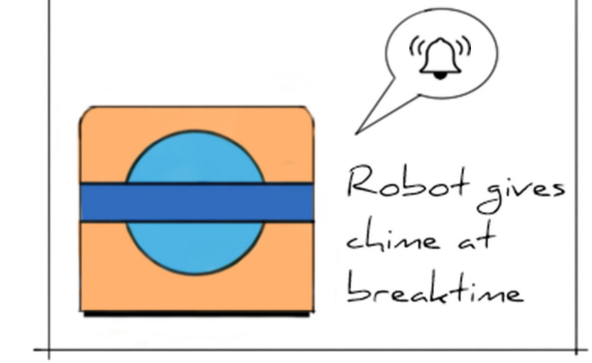



The robot acts as a regular scrubber-drier during worktime. At breaktime, it signals for building users to gather around a table that extends from the body, and dispenses drinks. People are encouraged to socialise and connect with each other, enhancing their experience of community and relatedness.

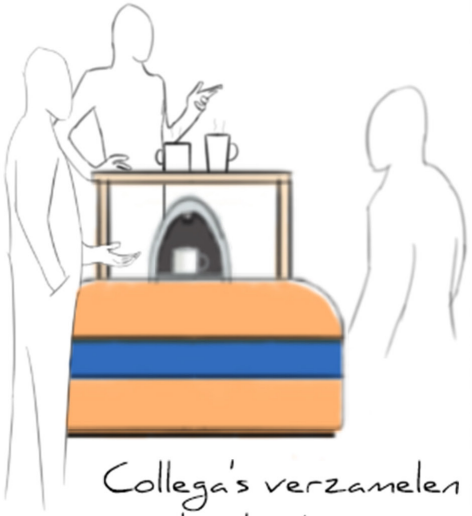


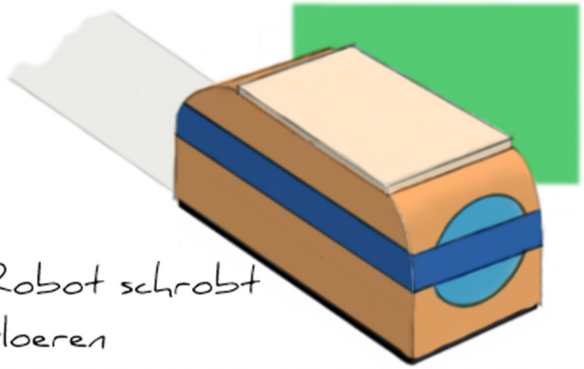



# Verbondenheid

De robot is gericht op het geven van een gevoel van gemeenschap en verbondenheid aan de mensen, en te ondersteunen in sociale interacties and relaties. De robot brengt gebruikers in het gebouw samen, en vormt een sociaal middelpunt.



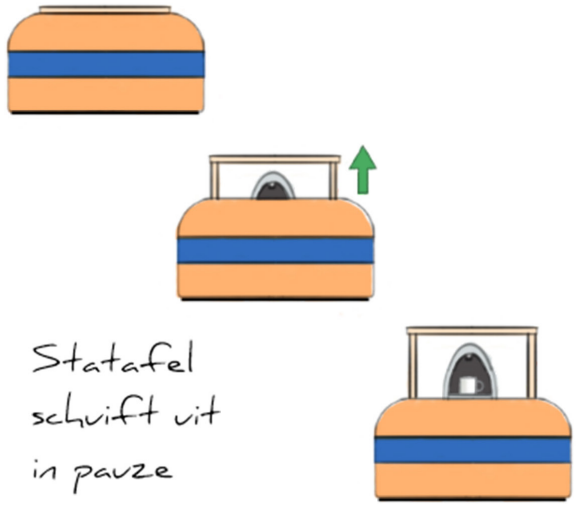
Collega's verzamelen rond robot voor verbinding



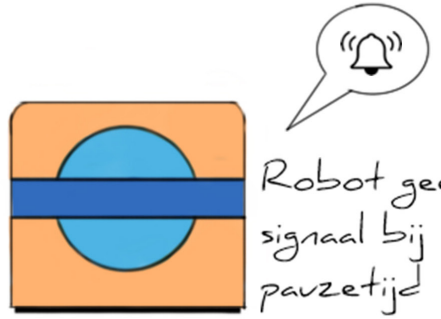
Robot schrobt vloeren

De robot werkt als een normale schrob-zuiger tijdens werktijd. In de pauze geef de robot een signaal om mensen in het gebouw te verzamelen rond de tafel die uitschuift, en verzorgt dranken. De mensen worden aangespoord met elkaar te praten en verbinden, om zo hun ervaring van gemeenschap en verbondenheid te versterken.

Robot kan koffie verzorgen



Statafel schuift uit in pauze



Robot geeft signaal bij pauzetijd

# Appendix C: Hierarchy role visualisations

# Tool

The robot acts as an effective tool for enhancing the capabilities of cleaning workers, enabling them to clean more effectively and expand their skills.

The user will be able to clean the floors more efficiently and effectively, while also maintaining their own health in the process.

The operator will need to calibrate the robot correctly to the planned routine, setting its sensors to avoid particular obstacles along the desired route.

The robot is usable as an instrument for monitoring cleaning activities, based on generated reporting. Using these measurements, the operator can change plans and routines where they deem it necessary.

# Hulpmiddel

De robot is een effectief hulpmiddel om de vaardigheden van de schoonmakers te vergroten, en het maakt hen mogelijk om effectiever schoon te maken en hun mogelijkheden te verbreden.

De gebruiker kan de vloeren efficiënter en effectiever schoonmaken, en daarbij ook de eigen gezondheid behouden.

De gebruiker zal de robot correct moeten calibreren om de geplande routine te volgen, en de sensoren instellen om bepaalde obstakels langs de voorziene route te vermijden.

De robot bevat instrumenten om de schoonmaak activiteiten te monitoren, en rapportage te genereren. Op basis van deze metingen kan de gebruiker zonodig plannen en aanpak aanpassen als zij dit nodig achten.

# Assistant

The robot loyally follows the orders of the human cleaner, acting autonomously to the specifications given by the operator.

The robot does the floor cleaning tasks that are not as interesting for the human operator. The operator only needs to check in occassionally to ensure everything is working to satisfaction.

The operator needs to show the robot how it should be working, and what route it should be following to do its job correctly. The operator will give these instructions during initial set-up.

The robot provides reports about its cleaning activities to its operator, who can use this reporting to assess the robot's results and make adjustments in its programming and instructions if this is deemed suitable by them.

# Assistent

De robot volgt loyaal de instructies van de menselijke schoonmaker op, en handelt daarbij autonoom naar de specificaties die gegeven zijn.

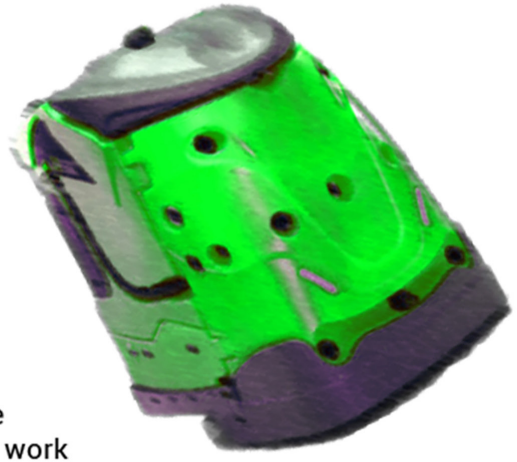
De gebruiker moet de robot laten zien hoe deze moet werken, en welke route gevolgd moet worden om het werkt correct te voltooien. De gebruiker zal deze instructies tijdens de eerste ingebruikname geven.

De robot doet de vloer reinigings taken die voor de menselijke gebruiker minder interessant zijn. De gebruiker moet alleen regelmatig checken of alles nog naar behoren functioneert.

De robot geeft rapporten over zijn schoonmaak activiteiten aan zijn gebruiker, die deze kan gebruiken om de prestaties van de robot te evaluëren en veranderingen te maken in de programmering als deze dit nodig acht.

# Colleague

The robot acts independently, as a co-worker and valuable member of the team. He works together with the human cleaner to get the tasks done together, making independent decisions about his share of the work.



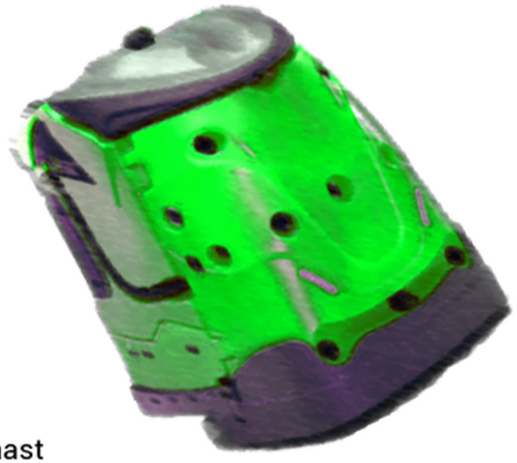
While the robot is cleaning the floors, the human cleaner can work alongside him on their own tasks in the area, and they can keep an eye on each other's work to make sure everything gets done right.

The human and the robot determine a suitable plan of approach for completing the cleaning tasks, dividing tasks and specifying how they should be done to achieve the best results.

Based on reporting that the robot creates about the team's cleaning activities, the human and robot collaboratively discuss how the work could be done better in the future, and make changes in their plans as necessary.

# Collega

De robot werkt onafhankelijk, als een medewerker en vol lid van het team. Hij werkt samen met de menselijke schoonmaker om de taken samen gedaan te krijgen, en maakt onafhankelijke beslissingen over zijn deel van het werk.



Terwijl de robot de vloeren schoonmaakt kan de mens naast hem werken aan de eigen taken in de omgeving, en kunnen zij elkaars werk controleren om te verzekeren dat alles juist gedaan wordt.

De mens en de robot bepalen samen een gepast plan van aanpak om de schoonmaak taken te voltooien, en verdelen de taken met specificatie hoe ze te volbrengen om het beste resultaat te behalen.

Op basis van rapportage die de robot maakt over de schoonmaak activiteiten van het team, kunnen de mens en robot samen bepalen hoe het werk beter gedaan kan worden in de toekomst, en hun plannen aanpassen waar nodig.

# Supervision

The robot acts independently and autonomously, overseeing that the work is done right. He can give the human cleaner suggestions for how to work.

The human cleaner has been instructed on how the robot is to be used, following set protocols for operation. Where needed, the robot can also provide signals for the human to take care of certain issues such as obstacles.

The robot takes care of cleaning the floors to the required level of cleanliness. Protocols and instructions are in place for what the human cleaner should be doing meanwhile.

The robot tracks how the work is done, and based on this creates reporting on the performance delivered at the end of the day. This reporting thereby specifies where the human cleaner will need to make improvements in the future to achieve better results.

# Supervisie

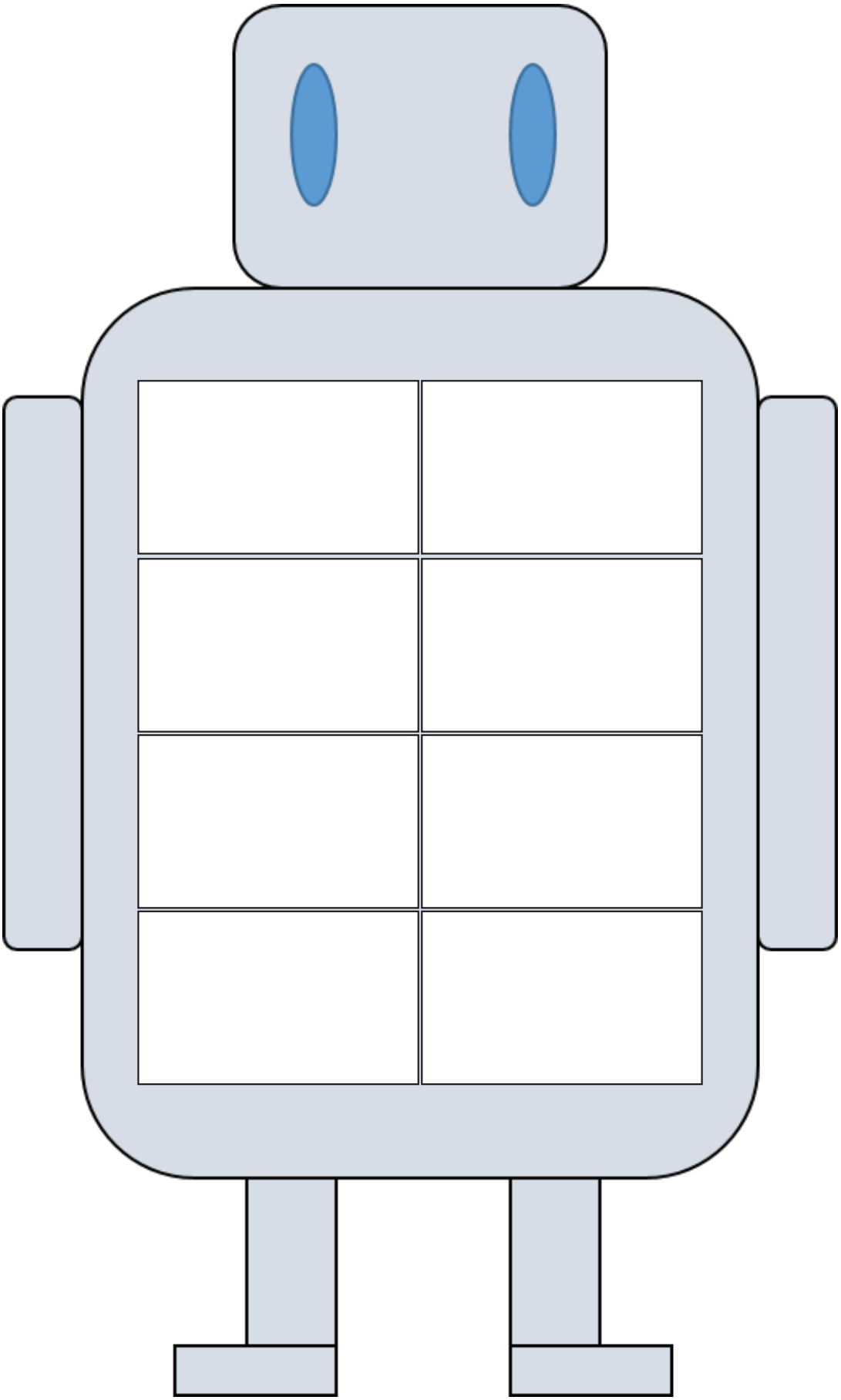
De robot werkt onafhankelijk en autonoom, en overziet dat het algehele werk juist gedaan wordt. Hij kan de menselijke schoonmaker suggesties geven voor wat te doen.

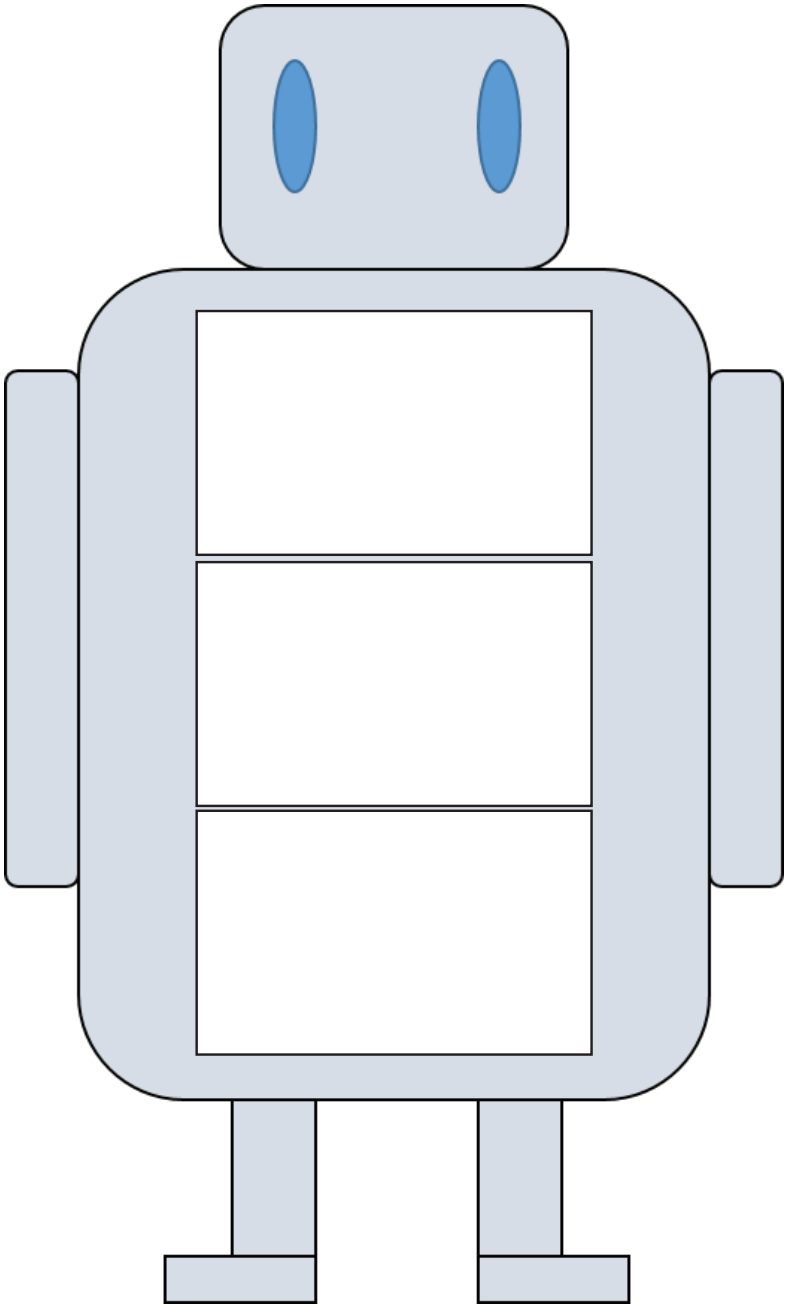
De menselijke schoonmaker heeft instructies voor hoe de robot gebruikt moet worden, en volgt de gegeven protocollen voor toepassing. Waar nodig kan de robot signalen geven voor de mens om in te grijpen, zoals bij obstakels.

De robot zorgt dat de vloeren tot het benodigde niveau schoongemaakt worden. Er zijn protocollen en instructies voor wat de menselijke schoonmaker ondertussen moet doen.

De robot houdt bij hoe het werk gedaan wordt, en maakt op basis hiervan rapportage over het werk dat aan het einde van de dag geleverd is. Deze rapportage geeft daarmee aan waar de schoonmaker verbeteringen kan maken om beter te presteren.

# Appendix D: Robot Puzzle (Physical)





| | | | | |
|---|---|---|---|---|
| Scrub Floors | Mop Floors | Vacuum Floors | Eliminate Dust | Detect Humans |
| Can Dance | Pick Up Trash | Make Coffee | Charge Itself | Remove Liquids |
| Clean Stains | Clear Desks | Generate Own Route | Dust Windowsills | Apply Disinfectant |
| Empty Trash Bins | Remove Cobwebs | Avoid Obstacles | Clean Toilets | Can Talk |
| Clean Appliances | Clean Windows | Scrub Sinks | Spread Air Freshener | Fill Soap Dispensers |
| Can Tell Jokes | Restock Paper Wipes | Play Music | Go Up and Down Stairs | |

| | | | | |
|---|---|---|---|---|
| Vloeren Schrobben | Vloeren Dweilen | Vloeren Stofzuigen | Stof Verwijderen | Mensen Detecteren |
| Dansen | Afval Oppakken | Koffie Zetten | Zelf Opladen | Vloeistoffen Verwijderen |
| Vlekken Schoonmaken | Tafels Opruimen | Eigen Route Bepalen | Vensterbanken Stoffen | Desinfectiemiddel Aanbrengen |
| Afvalbakken Legen | Spinneweb Verwijderen | Obstakels Vermijden | Toiletten Schoonmaken | Praten |
| Apparaten Schoonmaken | Ramen Wassen | Wasbakken Schoonmaken | Luchtverfrisser Verspreiden | Zeep Dispensers Vullen |
| Papieren Doekjes Vervangen | Grappen Vertellen | Muziek Afspelen | Trappen Op en Af Gaan | |

# Appendix E: Pilot Workshop Scenario Cards

## Future Expectations for Cleaning Industry Robotisation

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## ABSTRACT
The professional cleaning industry is a sector undergoing a shift towards robotic labour. Human cleaning workers will need to work alongside cleaning robots, which will have an impact on their work and the sector as a whole. To explore the expectations of cleaning workers of future cleaning industry robotisation, a scenario-based study was conducted with two human professional cleaning workers. Their contributions indicate a function-oriented view on cleaning robots, and an emphasis for workload reduction. The future design of cleaning robots is suggested to take into account an intuitive interaction, and ensure proper integration into the whole environmental context. There was little expectation for an improved public perception of cleaning work as a result of robotisation. Social features were not deemed relevant for cleaning robots by the participants.

## Keywords
Cleaning robots; HRI; Scenarios; Social robots

## 1. INTRODUCTION
An increasing number of industries and occupations are going through a paradigm change of replacing and enhancing physical human labour with the introduction of robots. These changes are driven by global trends like an aging population that have reduced the available human labour force (Biermann, Brauner, & Ziefle, 2021). When robots are introduced into the work environment, they will for the foreseeable future still be working alongside human labourers (Hinds, Roberts, & Jones, 2004; Lyons, Wynne, Mahoney, & Roebke, 2019). Human workers will for example be required to take care of tasks that the robots are incapable of doing, and for checking whether the robot is fulfilling its tasks correctly.

One of the industries that is undergoing the aforementioned shift towards robotic labour is the professional cleaning sector. One of the main reasons for that sector's interest in robotisation is that it involves a high degree of heavy physical labour that can put a significant strain on human workers (Kirov & Ramioul, 2014; Søgaard, Blangsted, Herod, & Finsen, 2006). This has driven the development of various kinds of cleaning robots (cf. Bormann, Hampp, & Hägele, 2015; Diversey, 2021; LionsBot, 2020). The main focus of these developments has been the alleviation of heavy and monotonous labour for human cleaning workers.

However, other concerns can arise when robots are introduced into the environment. The cleaning sector deals with a negative socio-cultural image, due to its association with physically tainted dirty work (Ashforth & Kreiner, 1999). The contributions of cleaning workers moreover can often be rendered invisible, as their presence and work is ignored by society (Rabelo & Mahalingam, 2019). Hypothetically, the introduction of robots could for example create public excitement and interest, and thereby enhance the esteem and recognition of cleaning workers. On the other hand, robots might render cleaning work more objectified and invisible, thus negatively affecting the status of the sector. Similarly, robots could place boundaries on the freedom and autonomy of human cleaners, as they are forced to work with the parameters imposed by a robot's technical needs and limitations (cf. Smids, Nyholm, & Berkers, 2020). At the same time, when robots take over the more monotonous and physically stressful tasks, this could give humans the freedom to focus on more satisfying ones.

These types of questions demand an exploration of the impact that the introduction of robots will have on cleaning work and the cleaning sector as a whole. Although cleaning organisations are the main decision makers with regards to implementing robots, it is the human cleaners themselves that will be mainly working with the robots. As such, for the responsible and effective design of cleaning robots, the perspective and wishes of cleaning workers should be taken into account. The expectations of human workers for robotisation can moreover indicate the current attitude towards cleaning robots, compared to theory provided by available scientific literature on robot co-workers. This paper therefore presents a study focussing on the following research question: *What are cleaning workers' expectations for how advancing cleaning robots will impact their work?* Answering this question will aid in the design and implementation of future cleaning robotics in an effective and responsible way.

In the following, there will first be an exploration of the background circumstances of the cleaning sector, and the potential impact of robots on work. Subsequently, the study design using a semi-structured interview based on scenario co-creation cards will be described. Finally, the results of the conducted study will be presented and implications discussed.

## 2. BACKGROUND
In this section, the current circumstances of the cleaning sector will first be discussed. Second, the current state-of-art of cleaning robots is described. Third, the impact of robotisation on work, on aspects such as meaningful work and good collegiality, as well as the domestication of robots, will be explored based on literature.

### 2.1 Cleaning sector
The professional cleaning sector is characterized by heavy physical labour. This has had an impact on the wellbeing and health of human cleaning workers. Great stress is placed on the cardiovascular and musculoskeletal systems of cleaning workers. As a result, shoulder and neck disorders commonly develop in long-time workers (Søgaard et al., 2006). The oftentimes monotonous and repetitive nature of cleaning work moreover places a degree of stress on the mental wellbeing of cleaning workers. To this end, the implementation of cleaning robots should not only focus on alleviating the physical workload, but also create a more mentally positive and satisfying work environment (cf. Spector, 1997)

Regarding public perception, the labour performed in the cleaning sector falls within the concept of 'dirty work.' It often consists of menial tasks and an at times servile relation to others that can be considered disgusting and degrading by the public (Ashforth & Kreiner, 1999). Within the categories of dirty work that Ashforth and Kreiner (1999) describe, cleaning work would be 'physically tainted,' due to its contact with dirty environments. It is also partially 'socially tainted,' due to the servile role that some organisations project onto cleaning workers. The taint from dirty work can lead to workers becoming 'invisible,' as their work becomes taken for granted and therefore unrecognized (Rabelo & Mahalingam, 2019; Vlasses, 1997). To deal with stigmatisation from dirty work taint, strong subcultures have formed in certain occupations, including cleaning, that enable positive internal identities to be formed and enable cohesion with colleagues (Ashforth & Kreiner, 1999).

According to Terskova and Agadullina (2019), an association with dirty work can in addition lead to worker becoming in part dehumanized and objectified. Objectification here refers to the workers being perceived by others to be equivalent to inanimate objects. Such objectification is likely to occur with dirty work that can be (partially) done by machines, since it creates the perception that the human is doing work a machine could be doing. This is therefore particularly an issue that should be kept in mind for the introduction of cleaning robots. That said, the introduction of robots could notably also have a positive effect on the public perception of the sector. This would for example involve the perception of workers shifting to be seen as operators of advanced technology, achieving greater results through use of a robot (Smids et al., 2020)

At time of writing this paper, the Covid-19 pandemic is ongoing, and it could be questioned whether there may have been an impact on the public perception of dirty work. An increased social significance on hygiene and cleanliness could improve the respect attributed to cleaning work. Indeed, the pandemic appears to have shifted certain stigmatized sectors into essential services, their workers becoming labelled as heroes (Mejia et al., 2021). However, according to Ashforth (2020), this shift is less pronounced for tainted dirty occupations than for occupations such as doctors. Whether the pandemic has improved recognition of the cleaning sector is therefore still debatable.

## 2.2 State-of-art cleaning robots

Various kinds of cleaning robots have been brought to the market thus far, displaying notable overlaps but also differences in their functionality and design. Studying these robots shows how human cleaners currently interact with robots, as well as the approaches that are taken in their design. It moreover illustrates the types of developments that are at present being focussed on within the industry. The robots discussed are chosen to be representative of the industry at present.

The Taski Swingobot (Diversey, 2021) (Figure 1) primarily scrubs floors, and is also capable of vacuuming. It uses inbuilt sensors to navigate, and to detect and avoid obstacles and humans in its path. Communication with bystanders and workers is done with light and audio signals. Bormann et al. (2015) have developed the Care-o-Bot 3 robotics platform into an autonomous cleaning robot concept (Figure 2). Their robot can plan its own route, and use sensors to measure whether cleaning is required in a particular location. It can use a vacuum cleaning attachment and empty trash bins through its mechanical arm. LionsBot (2020) have introduced a product family of cleaning robots named the LeoBots (Figure 3). Each individual robot has its specialisation, such as scrubbing floors and vacuuming. The robots form a team, supervised by a human cleaning worker. They are designed to have certain humanoid and social characteristics such as animated eyes and audio for simple expression.

**Figure 1 Taski Swingobot (Diversey, 2021)**

**Figure 2 Care-O-bot 3 Robot Cleaner (Bormann et al., 2015)**

**Figure 3 LeoBot Scrub (LionsBot, 2020)**

What these robots firstly have in common is that they appear to focus their cleaning tasks on floors, by scrubbing and vacuuming. In doing so, they appear to focus on taking over physically stressful and repetitive tasks. As mentioned earlier, these are the types of tasks that put the most strain on human cleaning workers' bodily and mental health. It can be said that the Care-o-Bot 3 and LeoBots display a higher level of autonomy compared to the Taski robot. Moreover, the LeoBots in particular can be seen to adopt a more human-like appearance through their form and interactions, particularly compared to the more machine-like aesthetic of the Taski robot.

## 2.3 Robot colleagues

Future workplaces are expected to increasingly involve robots and humans working together on tasks, each using their stronger skills, and relying on each other (Hinds et al., 2004; Lyons et al., 2019). When robots are introduced, they will therefore need to be integrated to act as good colleagues, since having good colleagues is an important factor for humans' wellbeing in work (Nyholm & Smids, 2020). Groom and Nass (2007) concluded that there remains doubt whether robots will be able to meet the expectations of humans to serve as true teammates. According to them, robots lack the mental model and social capabilities that humans demand from each other. By contrast, Nyholm and

Smids (2020) propose their own set of characteristics that good colleagues must display. They conclude that robots are at least in theory capable of meeting most requirements, though again there is doubt whether robots can display the necessary social features to be truly a good colleague.

As mentioned earlier, it is important for workers' mental wellbeing to be provided with satisfying work (Spector, 1997). One factor of work satisfaction is the workers' perception of their work as meaningful (Rothausen & Henderson, 2019). According to Smids et al. (2020), the introduction of robots could both inhibit or improve the meaningfulness of work. They argue that particularly when robots take over the most complex and difficult tasks, it can make human workers feel like their contributions have less purpose and challenge. Notably, this would contradict certain robotisation approaches, including some in the cleaning sector, that focus on relieving human workers of the most intensive and difficult tasks. As such, a proper balance of task division would need to be found, to keep the work meaningful. An alternative solution is the assigning of new tasks to human cleaning workers, though past attempts at such 'work enlargement' have historically also had negative effects on the sector (Calvet, Riel, Couture, & Messing, 2012; Søgaard et al., 2006). Smids et al. (2020) go on to posit that robots could inhibit the creative freedom of workers, as they are forced to follow the limited parameters of the robot rather than doing tasks the way they think best. On the other hand, the use of robots to perform the most arduous and repetitive physical tasks, could also enable workers more freedom and creativity for deciding over the remaining tasks that form part of their job.

In previous studies by Forlizzi (2007) and Fink, Bauwens, Kaplan, and Dillenbourg (2013), a robotic vacuum cleaner was successfully implemented into the social context of the home. In the domestic context, vacuuming robots can become accepted as social agents, even becoming anthropomorphised to a degree by having social traits and status attributed to them through names and responses (Forlizzi, 2007). Fink et al. (2013) found that certain users studied became personally attached to the vacuuming robot they received, as they adopted it into their home environment.

# 3. METHODS

The following section will describe the methodology used for an explorative study with professional cleaning workers. In the study, the participants were asked about their current experiences and future expectations regarding robotisation of their work. An approach using scenario cards was designed, in an attempt to facilitate collaborative and creative discussion. The overall design and procedure of the study will be described. The analysis approach for the study's results will furthermore be explained.

## 3.1 Study design

The study took a scenario-based design approach to explore the experiences and expectations of cleaning workers for the impact of advancing cleaning robots on their work, based on the methodology of scenario co-creation cards by Alshehri, Kirkham, and Olivier (2020). This methodology was chosen to encourage participants towards more speculative thinking about the future of cleaning work. A group of professional cleaning workers was invited to take part in the study through contact with their employer. The study was conducted with two participants. While this does not allow for statistically significant results, it was deemed sufficient for the explorative and qualitative nature of this initial study. The participants already had experience with an automated cleaning robot in their daily work, that could follow a pre-programmed route to clean floors. The study was conducted at the participants' workplace. The session was conducted in Dutch, as this was the preferred language of the participants.

The participants were asked to describe their expectations and wishes for what future cleaning robots would be capable of, and how the nature of cleaning work and the cleaning sector as a whole might change. To serve as inspiration, random scenario cards were drawn, showing robots or technologies, environmental contexts, and relevant values. Based on these cards, participants could collaboratively explore how certain kinds of robots might have an impact on them and their work. During the study, audio recordings were made of the participants' responses.

## 3.2 Materials

The primary materials prepared for the study were a set of scenario cards, based on Alshehri et al. (2020). The cards mainly consisted of photographs, to encourage participants to come up with their own interpretation and meaning to fit their personal ideas. Photographs were selected to be related to certain preconceived themes, such as differing degrees of human-like robots, while still being open to the participants to project their own meaning onto the images. Three decks of cards were made. The first deck contained images of robots and (representations of) advancing technology. Examples include photos of social robots (e.g. Pepper) and surveillance cameras. The images were chosen to be not explicitly related to cleaning tasks, and rather showed robotics and technologies from other fields. This was done to encourage participants to take an open minded approach to what might be possible. The second deck of cards focussed on potential environments and context factors that professional cleaning workers might encounter in their work. There were for example photographs of human cleaners working together to represent collegiality, and photographs of different kinds of workspaces that could need cleaning. The third deck of cards had phrases written on them, referring to specific values that may be at stake with robotisation of cleaning work. The third deck of cards was intended to only be used if those types of topics did not come up naturally, and more specific questions would be necessary. For this reason, specific phrases were chosen, so there would be no misinterpretation of what is meant. Examples of the cards used can be seen in Figure 4.

**Figure 4 Scenario cards**

## 3.3 Procedure

The study session took place at the workplace of the participants. Signed consent was asked from participants ahead of the session for their contributions to be used for the purposes

of the research, after being anonymised. Participants were informed through an information brochure that fully disclosed the procedure and purposes of the study. The session opened with a brief introduction to the project, and the goals for the workshop, informing participants that the session would be used to explore the potential social impact of advancing robotisation of the cleaning sector. They were also shown examples of existing (cleaning) robots, to make clear firstly what type of robots are of interest, and secondly what might be possible through advancing robotisation. The cleaning robots shown were the Taski Swingobot (Diversey, 2021) and the LionsBot LeoBots (LionsBot, 2020). They were informed that the audio of the session would be recorded, and the recording was started. Following this, the procedure for scenario development was explained to them as follows: random scenario cards would be drawn to determine a technology and context, and (if needed) focus topic; participants would then be asked to discuss for themselves how they think that situation would proceed. The cards were drawn by the researcher that was present. The researcher asked follow-up questions about topics that were unclear, as well as making sure all participants were given a chance to add their opinions. To close the session, the participants were thanked for their contributions and allowed to ask any remaining questions about the research they had. The audio recording was stopped. For ethical privacy purposes, the transcriptions made from the recording were anonymised, and the personal information of participants was not shared outside the study.

At time of conducting the study, regulations regarding the Covid-19 pandemic were in place. For compliance with the regulations, the session took place with 1,5 meter distance between the people present, that is to say the two participants and one researcher. Direct physical contact was avoided, and indirect contact was kept to a minimum by having the researcher manipulate the scenario cards. Both the researcher and the participants filled in a declaration form to indicate they had no symptoms of the Covid-19 virus, and hands were sanitized ahead of the session.

## 3.4 Analysis

As measurement, an audio recording was made of the study session, recording the participants' responses. This recording was analysed and coded based on a series of topics. A grounded theory approach was used for coding. The recording was first listened through, and emerging themes were noted down. Subsequently, all relevant statements and insights in the recording were categorised into these themes. Statements that were deemed unrelated to the topic of the impact of advancing cleaning robotics were not categorised and analysed. This resulted in the following categories being used:

*Current experiences:* This includes statements referring to the current situation of the participants. This category also includes statements made about the cleaning robot that participants already had experience working together with.

*Functional requests:* These are statements made about the developments that participants would like to see occurring in robots. Included are both of abstract and specific functions they would like a future robot to have and goals they would like to achieve.

*Future cleaning robots:* These are expectations voiced about what participants believed cleaning robots could be capable of in the future. This is for example the types of tasks they expect that the robots will be capable of doing, and where they might be applied.

*Future of cleaning work:* This category is used for statements regarding the developments in the cleaning sector that participants expect will occur as a result of robotisation. These are both expectations of how the contents of cleaning work will change, as well as how the sector as a whole could be affected.

*Relation to the robot:* This consists of statements about the participants' (social) relation to both their current familiar cleaning robot, and their expected relation to future ones.

# 4. RESULTS

In this section, the results of the conducted study will be described. Emerging issues in the designed procedure, and the impact thereof will first be discussed. Following this, the results will be structured and discussed according to the categories used for coding. For anonymization purposes, the two participants will be referred to as P1 and P2 respectively. Quotes from the recording presented below were translated from Dutch into English by the author.

## 4.1 Procedure

During the session, it became clear that the planned approach using the scenario cards was not having the intended effect of encouraging collaborative scenario development. As such, as the session proceeded there was a shift towards a semi-structured interview approach. The cards were from then on used mainly as inspiration for the questions to be asked and topics to address. The reason the cards did not have the intended effect could be because the participants were less familiar with that type of collaborative design tool, and the associated creative thinking framework. They may have moreover had pre-existing expectations going into the session that made them focus on their personal context and the robot they knew already, which made them resistant to the cards that suggested different contexts and technologies. The regulations in regards to Covid-19 may have also played a role, since they meant that there was a greater distance between the participants and they were not able to manipulate and look at the cards together. Instead, they had to pick them up for themselves, and then hand them to each other, which may have caused a more individualistic experience.

## 4.2 Current experiences

The participants described the relation to their current cleaning robot to be mainly functional. The current robot, in their words, replaces so-called 'dead work,', that is to say work that is very boring and repetitive if a human does it. In the example of their current robot, a human would have to push or sit on a large machine to drive back and forth along a broad hallway to scrub the floors. Notably, P1 described that particular task as being very fun for new cleaners to do, as they get to drive around on a big machine. However, he described that the task gets very boring and repetitive when he has to do it every week or even multiple times a week. Both participants were therefore glad that the robot could do that particular task so they could do other things: *"It's a kind of collaboration with the robot, rather than it taking the work from you" (P1)*. The human and robot divide the work between themselves. They found that this even allowed for improved results. In their perception, the robot for example does not have the human shortcoming of forgetting to do certain areas. As a result, *"[often] the quality is even better, than if you had done it by hand" (P1)*. The robot therefore is perceived as having added value for the overall performance of the cleaning tasks.

Participants described other tasks they perform that they also deemed 'dead work,' or as the type of heavy labour that could

be automated. They for example described the cleaning of large windows, and the cleaning of grates that get dirty from grime due to nearby machinery. These are cleaning tasks they currently still do, that they deem similarly 'dead' as the scrubbing of floors.

The environment the participants work in consists of both industrial areas as well as office spaces. In this environment, the participants repeatedly described themselves to be 'guests' who have to follow the wishes and instructions of the 'host,' that is to say their client. In this environment, there are different kinds of people walking around, which the robot has to avoid through its inbuilt sensors: *"It's normally not just us that walk around here, but also employees. There is also guided tours and such, and the robot then walks between the people" (P1)*.

## 4.3 Functional requests

Throughout the session, the participants voiced various requests for capabilities they would like to see in future cleaning robots. Some of these concern very specific features or tasks: *"I've heard about robots that can for example also clean windows and clean facades and those kinds of things.[…]If there were a robot we can put on that, that would be really nice" (P1)*. A further idea expressed was to address how currently the human cleaners have to manually push the robot to the designated starting point. This is a point that was programmed in when the robot was implemented. From there, the robot can start its route, and it returns there when finished. The human cleaners then have to push it back to its storage closet manually, and connect it to its charger. *"Maybe an idea, that like a vacuum robot that has its own docking station, it drives off its docking station and does its thing and then it drives back" (P1)*. Another common issue that the participants expressed encountering is that the robot can get stuck along its route, for example due to an error with its sensors. Currently they either notice this kind of problem by chance if they walk by, or they only notice when they see the robot has not returned to its starting point. This can lead to loss of time, as the robot either has to do the rest of its route, or the human does it instead. With this in mind, participants expressed that *"[it] would be nice if the robot were connected to a phone, that if he then gets stuck, he can communicate 'Listen, I have a problem'" (P1)*. Such a notification should be fairly dry and to the point according to the participants: *"Just a beep or an alarm, so you know 'Oh, there's something wrong with the robot', so you go there to check,"(P2)* and "*Very simple. 'Error. This is what's going on.', it doesn't have to be very elaborate"(P1)*.

The participants also expressed comparatively more abstract goals and wishes they have for cleaning robots. Overall, they wish for a robot to take over undesirable tasks: "*It needs to support us. Like I said, the reason we have a robot is for 'dead work'"(P1)*. They deem this particularly important, first because those 'dead work' tasks are physically stressful, causing health risks to long-time cleaning workers. Second, the repetitiveness has a mental component to it as well, and makes time spent on the task feel wasted: *"It kills the spirit. It would be better if I can put my head elsewhere and do something else"(P1)*. By taking over those tasks, *"[it] allows us to do different work" (P1)*, namely work that is more interesting. This could entail tasks that the robot is incapable of doing, such as corners and tables. P2 also expressed a desire for reliability of cleaning robots. Referring to their current cleaning robot: *"It can be nice and convenient, but it can also happen that it breaks down and we have to wait for repair. It is give and take" (P2)*. Overall, the robot must have an added value, by making their work easier. Both participants expressed in unison: *"It has to lighten the workload"(P1 and P2)*

Regarding the interaction with the robot, participants emphasised a preference for simplicity: *"I would recommend that it be as simple as possible, because not everyone can work with it very well"(P1)*. This was first in reference to the programming of the robot. The robot that is currently in use had to have its specific route programmed in by hand by a technician on location. If human cleaners would at some point be asked to do this themselves, it would need to be very easy and intuitive, according to the participants. Maintenance should similarly be easy, and automatic where possible. They would prefer to have as little work as possible doing for example updates, also because they expect not everyone is good at that. This would also ensure that there no longer needs to be a 'specialist' amongst the cleaners who always takes care of the robot: *"Right now, there is one or two people who deal with the robot, and everyone else keeps their hands off. But it should be that if they are not there, someone else can work with it and know how to do it"(P1)*. One additional idea that they expressed together is for the robot to be activated and controlled through a mobile phone. According to them, this could make the interaction with the robot easier and more accessible for others. Such a connection to the cleaners' phones could also integrate the aforementioned feature suggestion for error messages with clear information about problem and location.

## 4.4 Future cleaning robots

The participants mentioned various expectations they have of what future cleaning robots will be capable of. Several tasks were mentioned, which participants doubted a robot could perform: *"When it comes to cleaning desks or tables, I don't think that is something that a robot could do"(P1)*. When prompted about future robots' potential capacity for those tasks, they argued for different tasks that only a human could then do: *"If you could develop that, fine, then I will put the robot on the table so I can do corners and ledges"(P1)*. Overall, the participants appeared to expect that truly advanced cleaning robots that are capable of a wide range of thorough cleaning tasks are still far off in the future. In response to deeper questioning based on robots shown on cards as well as a robot shown in the introduction to the session: *"[With some of these robots] you are I think five steps further than where we are at right now" (P1)*. Moreover, robots that are capable of fully taking over all cleaning tasks appeared to be deemed unlikely by the participants.

As a consequence of this, participants expressed an expectation that there will always be a need for a human in cleaning. Even if a robot could somehow do all the cleaning tasks, they argue, you would still need a human to check the work and results. Moreover, a human is expected to be needed to clean the robot itself and do maintenance, since the robot cannot do this by itself. In this sense, the participants see future cleaning robots still mainly in a support role, and like it that way. Describing his positive outlook for cleaning robots, P1 mentioned *"I am a proponent of robotisation, because it helps. It supports you, and that is really nice."*

## 4.5 Future of cleaning work

Participants discussed the tasks that they could foresee human cleaners doing in the future, when there are more advanced cleaning robots. For the cleaning itself, they expected that the work of humans could become more about turning the robot on and keeping it going. They can then focus on dealing with remaining areas that the robot cannot do. According to P1,

*"meanwhile I will do the sides or similar areas."* When prompted for tasks outside of cleaning, they described it as *"difficult to imagine"(P2)*. P1 did insist *"I am not going to mow the lawns"* or similar physical activities. They thought that maybe a robot could give them more time for tasks such as checking for broken lamps or switches, or damaged windows and doors. However, they mentioned that these are already part of their work tasks, and would therefore not be new. When asked about the potential of performing certain hospitality tasks, they argued *"[as cleaning workers] we already are kind of hosts and service providers"(P1)*.

Largely, participants leave decision making about their tasks to their employer and the client: *"In the end, [the client] has to offer it to us to get additional tasks"(P2)*. They also caution against assigning too many (new) tasks to cleaning workers: *"It's nice when you can do as much as possible for a client, but it also has to end somewhere"(P1)*. This also has to do with some people just not being good at certain tasks, or them not being what they signed up for when they chose to become cleaners: *"If I wanted to [mow lawns], I would have become a gardener" (P1)*. This is moreover compounded by the other service providers that also work in the building. Workers in catering or maintenance also do many tasks, and participants expressed it seemed impractical for cleaners to take over those tasks. Finally, they feared that too many tasks for cleaners can become overwhelming, as they have too much to keep track of: *"The more you have to do, the more you are going to forget. And that can also lead to complaints"(P1)*. They added that having to keep track of many tasks can be mentally taxing, which can eventually also become a physical problem.

For the sector overall, they expect that robotisation could enable workers to stay in the industry longer, since there is less physical strain and problems for humans. Regarding the question whether the work would still be satisfying with robots, P1 got agreement from P2 when he stated *"I would rather be lazy than tired."* That is to say, they prefer the job to be as easy as possible. They did stress that this can be very personal, and they expect that some people might feel like there is nothing left for them to do. They added that if in the end, there is nothing left for them to do, their employer will put them in a different location, or costs would be cut in some other way. They expressed a feeling of inevitability regarding this, it being a trend they cannot stop: *"This is where we are going with robotisation. You won't be able to stop it. And in the end, where robots are working, there will also always be humans working to keep the robot going and check if the work is going well"(P1)*.

The participants did not expect that robotisation would do much about the currently often negative perception of cleaning work. According to P1 *"When you say cleaning, you are already at the bottom of the ladder, and then it doesn't matter whether there is robots or not.[…]Cleaning has a certain association, and that won't just change because of robotisation."* They found that in the beginning, there was a lot of curiosity and excitement at their worksite, namely from the client's employees. They would ask about all the things their current robot can do. That excitement ended after some time however: *"It becomes normal, as they get to know it"(P1)*. For this reason, they do not expect that robotisation will lead to more recognition and respect for cleaning. That said, they also did not expect robots would lead to a more negative perception, due to for example objectification. They argued that the perception will remain the same, because humans still have capabilities that robots do not have.

## 4.6 Relation to robot

The participants mainly regarded the concept of a cleaning robot as a support, to take over certain physically stressful or monotonous tasks: *"As a man, you sometimes have to do physical labour. But if a robot can take it over, then why wouldn't you do that? It's in the end an addition, and not like it takes your work from you"(P1)*. They liked the notion that a machine can keep working while the human takes a break: *"The robot just does its work while I am having my coffee break, and I can just do whatever I want"(P1)*.

There was largely scepticism regarding the idea of a cleaning robot having social capabilities and features. P1 responded to a video in the introductory presentation, showing the comparatively human-like LeoBots cleaning robot interacting socially with humans: *"This one also has interaction with the human which is fun. But if it really has added value for a cleaning organisation I would not say."* P1 went on to bring up a cleaning robot he had heard of that was used in a hospital: *"A robot can be really interesting for children. […]In a hospital it can be nice, when there is children that can play with the robot. But here [at the current client] it does not make sense."* Both participants did not deem social features to be relevant for their personal work environment. They did note that this can be a personal preference: *"For me it doesn't need to be very human-like. But that is my own personal preference. There's probably people who do think it would be nice when they are spoken to"(P1)*. Here they also again emphasised the role their client has for deciding what a robot should be doing: *"And it is also very much up to what [the client] wants. We are guests here, and we have to keep to their wishes"(P1)*. They also did not deem it necessary for the robot to concern itself with matters of collegiality: *"With the options we have through mobile phones, we don't need a robot to act like an intermediary"(P1)*. Overall, the participants seemed critical of the robot doing more than was purely functionally necessary for cleaning, summarised strongly by P2: *"We are here to work. The robot should do that too."*

The participants appeared to largely reject the notion of cleaning robots becoming more human-like. That said, there were some statements made that could be interpreted as ascriptions of human-like characteristics to even their current robot. In response to the video in the introductory presentation, P1 said *"This looks far more like a human."* Regarding their current robot, which does not look very human, there were still some potentially anthropomorphising perceptions. P2 said *"When the robot takes over the heavy work, it sometimes gets 'tired' or broken, and then we still have to do it"*, using the concept of tiredness to express the robot breaking down. P1 at one point chose to implicitly use the metaphor of 'sickness' for a robot: *"A machine is a machine, and something can always break. A human also sometimes gets sick [in a similar way to the robot]."*

# 5. DISCUSSION

Overall, the participants appeared to take a fairly mechanistic and function-oriented perspective to robotisation. The main recurring emphasis was on reducing the workload as much as possible, to allow human cleaner to focus on lighter and more engaging tasks. A lot of arguments and statements were made referring to their current context, and the possibilities for robot capabilities at that moment. This can be seen in the types of features that participants mentioned as being desirable. These were largely solutions to problems they personally encountered regularly in their daily work for that specific client. Other suggestions came from robots they had personally heard of or

encountered in the past. It was comparatively more difficult to get more far-reaching suggestions, about directions that could be taken towards a longer-term future. In regards to this, such thinking was repeatedly left over to the participants' employer and client to make decisions about.

Emphasis was placed on interaction with and usage of a cleaning robot needing to be as simple and intuitive as possible. This was largely in reference to the (limited) technological understanding and capabilities that participants ascribed to their co-workers. On the one hand, this can speak to a need for straightforward and intuitive interactions and user interfaces to be designed. It should be noted however that the participants may have also underestimated their colleagues' capabilities, and partially also their own capabilities. Besides the interaction with human cleaning workers, the participants' contributions indicate that the entire environment needs to be taken into account. In working contexts similar to theirs, there are non-cleaning employees and sometimes even guests walking around. These environmental circumstances need to be taken into account for proper integration of a future cleaning robot.

The way that participants described how the human and robot divide the work amongst themselves aligns with the works of Hinds et al. (2004) and Groom and Nass (2007). They argued that an effective integration of robots into the workplace should involve humans and robots each doing the separate tasks they are particularly suited for. According to Smids et al. (2020), such an effective division of tasks can moreover lead to better results being achieved, which is also an observation participants made. Smids et al. (2020) add to this that if the results become better, this can make the human workers feel like their contributions are more meaningful and raise their self-esteem, since they are achieving greater quality. The participants implicitly also displayed such increased self-esteem in the way they described their use of the robot.

Participants appeared to have a largely positive outlook towards robotisation. They considered it to have added value to them by alleviating physically stressful and boring tasks. P1 repeatedly described himself as a proponent of robotisation. There was no apparent anxiety about losing work, since they believed there would always be a need for humans to do certain tasks and check the robot's performance. Some of the participants' responses can moreover be interpreted as being sceptical of robots' potential capabilities. There appeared to be a strong expectation that cleaning robots would be unlikely to ever be capable of very specific and detailed cleaning tasks. For example, they did not expect robots could in the foreseeable future clean tables or narrow corners. Underlying this, there was also a perception of robotisation being inevitable. The participants did not believe they could do anything about robots being introduced, which can be seen as a normatively technologically deterministic view (cf. Dafoe, 2015; Kline, 2001). Related to this is the role they repeatedly ascribed themselves in the environment, namely that of a guest in the client's building. As a side-note, these statements do contrast with P1 at one point also describing the cleaners as hosts themselves. They did on the whole emphasise leaving larger decision making for what is wanted and needed to employers and clients to figure out between themselves. This could imply a certain sense of passivity on the part of the participants. It should be noted that this could be personal to them, and that they themselves did not appear to see this as a problem. Rather, they described a goal-oriented personal philosophy of going to work, getting your tasks done, and then you are done and go home. This potential experience of low decision-making power on the part of cleaning workers could warrant further study.

Regarding the larger scale consequences for the public perception of the cleaning sector, the participants appeared highly sceptical that robots could have an impact. According to them, the excitement that robotisation may elicit would likely not last very long. They described that the curiosity that their robot got from others became less significant over time. For future cleaning robot designers, this could however also be considered a viable challenge: how to design cleaning robots in such a way that excitement, novelty, and interest from the public lasts longer? For such a challenge, it could for example prove fruitful to take into account the role that media and societal narratives can play for the perception of robots (cf. Payr, 2019).

Apparent through the responses of the participants was also a high degree of scepticism for cleaning robots' potential social features. The participants did not see a need for such design directions, at least not for their particular context. The examples they came up with for where social features and human-likeness could be relevant notably had the social interaction occur not with human cleaning workers, and rather with for example children or guests. However, some attributions of human-like qualities were made by the participants, also towards the comparatively mechanistic cleaning robot that is currently in use. It should be noted that within the context of the session, ascription of concepts like the robot being 'tired' or 'sick' could be interpreted as being intended as metaphors or irony. However, they could still serve as indication that there is a small degree of mental association present. These topics could be explore further in future research, for example through the lens of media equation theory (Reeves & Nass, 1996). On the whole, it however appears that the relation between the professional cleaning workers and their robot has not reached a level of social adoption similar to that described for domestic cleaning robots by Forlizzi (2007) and Fink et al. (2013).

The conducted study has a considerable limitation due to the low amount of participants at two. Moreover, both participants worked in the same workplace, and had previous experience with the same robot. As such, the results of this study cannot be assumed to apply broadly across the cleaning sector for other human cleaning workers. It could be speculated that cleaning workers that do not have experience working with a robot might display comparatively more unrealistic and futuristic expectations. This is because their perspective would not be based on current practice and robot capabilities. They would likely still argue however from the basis of their personal work context, and the problems they encounter there. P1 gave comparatively more substantial responses during the session, relative to P2. As a result, comparatively more quotes and contributions discussed in this paper came from P1. Though there was apparent strong agreement between the participants, this may still have further skewed the results to have higher weighing of P1's contributions. The results discussed therefore should be interpreted as explorative suggestions, and as additions or contrast for similar studies. As mentioned earlier, it should also be taken into account that the study was conducted under distance regulations due to precautions against Covid-19. This may have impacted the overall tone and collaborative nature of the session. Moreover, combined with the overall attitude and expectations of the participants, these regulations may have impacted why the planned approach that made more substantial use of scenario co-creation cards did not achieve the planned results.

## 6. CONCLUSIONS

The study presented in this paper has aimed to explore the expectations of cleaning workers for the impact of robotisation of the cleaning sector. Its main contribution is that these expectations should support the design and implementation of future cleaning robots in an effective and responsible way. Two participants were interviewed about their ideas and expectations. This resulted in a series of observations and implications for the design and integration of future cleaning robots.

The participants displayed a strongly function-oriented view on cleaning robots. They prioritised a robot that purely takes over the most difficult or boring tasks. Interactions and interfaces should be straightforward and intuitive for people with less technological literacy. The entire environment in which the robot will function should moreover be taken into account. Both in literature and responses from the participants, great importance is placed on the teamwork dynamic of human and robot each doing the tasks they are best suited for to divide the work effectively. This should lead to better results being achieved, and to the cleaning workers feeling greater pride and satisfaction in their work. There is potentially a lack of decision-making power on the part of the cleaning workers, as participants repeatedly described robotisation as inevitable and that a lot of decisions are made by their employers and clients. Any potential improvement of the public perception of cleaning work is expected to be only short-term, as cleaning robots become normalised unless excitement and curiosity are made to last. The participants did not show interest in the notion of cleaning robots becoming social agents with the entailing features. Nonetheless, there were indications of certain mental connections existing for a robot to be considered more human-like. As such, while this is not the case now, it could be possible in the future that cleaning robots become socially adopted in a professional environment, similar to how their counterparts have been adopted into the domestic environment.

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