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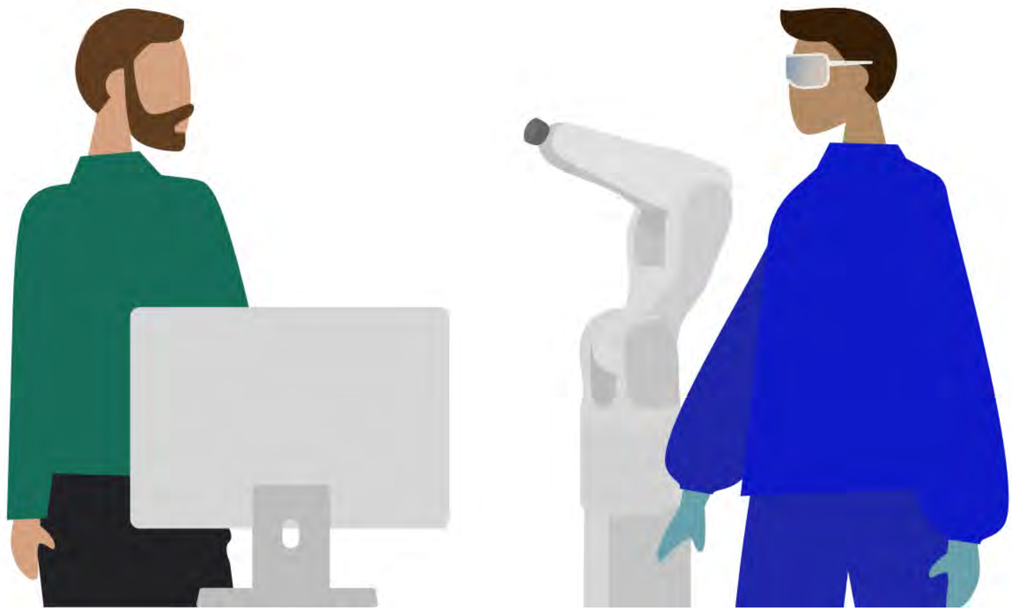

UX aspects of interaction with a system of collaborative cleaning robots

A speculative design study investigating how interaction with a system of mobile and collaborative cleaning robots should be designed to support the users' experience during configuration and operation

Master's thesis in Interaction Design and Technology

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Gothenburg, Sweden 2022

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Cover: Illustration of the two key user roles, a system configurator and a system operator.

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Abstract

The possibility of developing a system of mobile and collaborative cleaning robots to assist human workers with the cleaning of food plants is currently under investigation. This master's thesis aims to identify the future key users of a robot system, and takes a speculative design approach to investigate how the interaction with this system could be designed to support a good User Experience in the future 10 years from now. To gain an understanding of the system of robots and the intended users, their tasks, and the food plant context, the focus was initially put on user studies and data gathering. Two key user roles could be defined: system configurators and system operators. Thereafter, the interaction between the key users and the robot system was explored. Regarding system configuration, a suggestion on how a system configuration procedure could look in the future was developed and presented using a Hierarchical Task Analysis. Regarding system operation, four different speculative interaction design concepts were developed and presented using storyboards. The Hierarchical Task Analysis and the storyboards were subsequently evaluated with intended future key users, designers, and stakeholder companies. Finally, 11 design recommendations for interaction design could be derived. Cases exemplifying a speculative design concept for interaction design based on these recommendations were also further demonstrated through two future scenarios.

Keywords: Interaction Design, User Experience, Human-Robot Interaction, Human-Robot Collaboration, Speculative Design, System Configuration, Industrial Cleaning, Food Industry.

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Anna Grafström & Moa Holmgren, Gothenburg, May 2022

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Introduction

Cleaning food plants is challenging. The work environment and work tasks are rough, and recruiting workers is getting increasingly difficult. In addition, Lelieveld et al. [1, p. 447] argue that highly efficient and sustainable cleaning methods which meet the high standards of hygiene in food production are requested. To face these arising challenges, the possibility to complement human cleaners with mobile and collaborative cleaning robots is now investigated.

Müller-Abdelrazeq et al. [2, p. 101] describe how human-robot collaboration can increase efficiency and simultaneously reduce costs in comparison to fully manual as well as fully automated solutions. Humans are superior to robots when it comes to problem solving, flexibility, and creativity, but robots perform better when it comes to consistency, repetitiveness, precision, and power. By combining the advantages of both humans and robots, new and improved ways of working can be developed within many contexts. The cleaning of food plants has a great potential to become one of these.

Thus, the RoboClean Research Project, which is further described in section 2.1, has been initiated. The aim is to combine the strengths of humans and robots, and thereby improve the overall cleaning procedure with regard to effectiveness, efficiency, reliability, and sustainability. The RoboClean Research Project investigates the future possibilities for a system of cleaning robots assisting human workers and taking care of rough tasks with high efficiency, while human workers supervise the robots and take care of any tasks that a robot is not capable of.

1.1 Research Problem

Within the system of cleaning robots investigated in the RoboClean Research Project, humans will be central. Humans will configure how the system of robots functions and humans will further supervise as well as collaborate with the system of robots while operating. Thus, there are several key user groups interacting with the system of cleaning robots in different contexts and with different purposes, giving rise to a need for interaction adapted for the various users and their work situations. Owing to the interactive nature of the robot system, User Experience for the different key user groups will be crucial.

User Experience puts the user at the center of all considerations, as stated by Nichols and Chesnut [3, p. 8]. Sharp et al.[4, pp. 15–16] argue that understanding a specific user group and their context is the key to understanding how to design for the requirements and needs of users in this context as well as for a good User Experience. By collecting knowledge about people and their behaviors in a certain context, incorrect preconceptions and faulty assumptions can be prevented.

In this initial stage of the RoboClean Research Project, two different key user roles are predicted to be interacting with the system of robots primarily. These are the system configurators and the system operators. System configurators will be involved during the initial configuration of the system of robots and will adapt the system for a specific food plant. The system operators will work with the daily cleaning of food plants and supervise as well as collaborate with the system of robots on a daily basis. Accordingly, these two primary user groups are interacting with the system at different times, in different contexts, and with different goals. An understanding of these two key user roles will be crucial when designing for a good User Experience.

However, since the system of cleaning robots is yet only a subject of research on a conceptual level, no actual users exist yet. To define the user roles and their tasks in this future vision, the researchers will therefore gather knowledge about present user groups working in similar contexts and/or with related tasks, to craft speculative design suggestions for the future. Speculative design is, according to Malpass [5], a design practice exploring possible futures with a focus on emerging technologies and science. Auger [6] further describes speculative design as a tool stretching the boundaries of reality to envision design concepts and enable discussion, unrestrained by the limits of what is technically possible today. Arguably, speculative design theory thus makes a good match for this master's thesis to explore the future of this system of cleaning robots.

Auger [7] further describes a method for speculative design called the ecological approach. This method concerns speculative design for a certain, known context, and thus seems to align well with User Experience where the emphasis is put on understanding the users and their context. When making use of the ecological approach, designers must know the context and work with the requirements the specific context sets for the design, and this will in turn create a bridge to anchor the speculative design in a relatable reality. Also within User Experience, Chu [8] argues that context is central. The context prescribes the needs of people, and the User Experience of a product is therefore highly dependent on the context in which they are used. Thus, speculative design with an ecological approach does not only have the potential to support the creation of strong speculative design concepts, but also support User Experience.

As the system of cleaning robots in the RoboClean Research Project is the first of its kind, this opens up a wide unexplored field of research. Nonetheless, related work looking at other types of cleaning robots has been conducted. Bitonneau et al.[9] studied a cleaning system for a pyrotechnic tank to replace the physically demanding manual cleaning, Yin et al.[10] researched a Human Support Robot system designed for food courts that detects food litter and cleans tables, and Gambao and Hernando [11] looked at a system of robots developed to perform cleaning of building facades semi-automatically with assistance from humans. Further, research considering aspects of User Experience in Human-Robot Interaction have been conducted by Prati et al. [12], Prati et al. [13], Chowdhury et al. [14], and Kadir et al. [9] among others and is also of relevance for this project. Moreover, Bragança et al. [15] and Schmidbauer et al. [16] have described the different user roles in relation to a collaborative robot, and both Lee et al. [17] and Wilkinson et al. [18] have described Design Aspects in Human-Robot Interaction, where the Interaction mode is of special interest for this work. Research on how to design for multiple user groups is also of interest for this work when considering the diverse key user groups, and this has been pursued by Renaud et al. [19], Wasson et al. [20] and Jul et al. [21]. Robot system programming and integration is also of relevance, and Schmidbauera et al. [16], Rossano et al. [22] and The International Federation of Robotics [23] have done research in this area. Finally, a speculative design approach has been used by Sengupta and Kant [24] to comprehend the User Experience of industry 5.0 in the future and derive recommendations for design in this future context.

In conclusion, the RoboClean Research project is pioneering within its field, and no research on User Experience has yet been conducted for systems of mobile collaborative cleaning robots. Two key user groups have been predicted to play central parts, and the interaction between these users and the system of robots will thus be the main focus of this study. Since the system of cleaning robots yet only exists as a concept for the future, speculative design has been found suitable for investigating possible interaction modes for the cleaning robot system to support a good User Experience.

Relevant research on other systems of cleaning robots, as well as research from different parts of the Human-Robot Interaction field, exists, but there is a lack of User Experience oriented research covering systems of cleaning robots in the food industry. In addition, no study looking into the User Experience of mobile, collaborative cleaning robots has ever been done before owing to the novelty of this concept. The aim of this master's thesis is therefore to fill this research gap by studying how interaction with a system of mobile collaborative cleaning robots could take place in the future, and how this can support the user's experience during the configuration and operation of the system in the food industry.

1.1.1 Research Question

To explore possible interaction modes of the system of cleaning robots investigated in the RoboClean Research Project and describe how this interaction might take place in the future, the following research question was formed:

How should the interaction with a system of cleaning robots be designed to support the users' experience during configuration and operation?

The answer to this question will be given in the form of design recommendations for interaction during system configuration and system operation. Further, these design recommendations will be exemplified through a speculative future scenario describing how a system configurator and a system operator could interact with the system of cleaning robots.

1.2 Purpose

The purpose of this master's thesis is to identify how the key users will need and/or wish to interact with a system of cleaning robots around the year 2030. Therefore, it is necessary to investigate the current cleaning situation in the food industry and identify what requirements this context puts on a system of cleaning robots from an interaction design perspective. The different users of the cleaning robot system must be identified, and typical interactions and workflows will be described for the key user roles. Additionally, the capabilities and constraints of the system will be taken into consideration when defining user roles and tasks. Speculative design concepts for interaction with the robot system will be explored, defined, and evaluated with potential users and stakeholders. Design recommendations for interaction design will be derived from the needs and wishes of these users and based on these, the interaction with the system will be demonstrated through scenarios.

The goal is to create an understanding of a possible future where food plant cleaning is performed by humans in collaboration with robots. Further, the goal is to envision and empathize with the key users in this future context, their work situation, and their needs and requirements for a system of cleaning robots. Emphasis is put on understanding the key users who will interact with the cleaning robot system primarily, and how the system of robots can support their work. Additionally, this project also aims to lay a foundation for future User Experience design work within this area.

1.3 Research Contribution

This master's thesis contributes to the research field in multiple areas. First and foremost, by answering the research question this thesis contributes with guidelines on how to design the interaction for a system of cleaning robots. However, as this project to the best of our knowledge explores a new field, we believe that the findings from our study can be valuable in related projects as well. The data gathered about the cleaners, their work situation, and the context of a food plant is of relevance when designing any product for this user group or in this context. In the process of answering this research question, the methods used along the way has also resulted in additional process results, and we believe that these also can be of relevance when designing for this user group or in this context. For example, the list of requirements contributes with requirements for Human-Robot Interaction as well as for the Configuration software provides a useful guide for future design work in this field. Thereto, the outcome of evaluations of concepts for HRI can provide valuable insights for interaction in this environment, as well as the future of HRI in general.

1.4 Delimitations

The focus of this project is delimited to the key users interacting with the system of robots. In this report, these user groups are referred to as system configurators and system operators. Other user groups that also might interact with the system, but less frequently, such as cleaning experts, producers of cleaning equipment, and system supervisors in the food plant will not be considered in this study. Furthermore, the number of people working with the configuration of a system of cleaning robots could vary. Similarly, there could be multiple robots cleaning in the same food plant, or multiple system operators collaborating with the same robot. However, this study is delimited to a case where only one system configurator is working with the configuration. Likewise, the focus is further delimited to a case where only one system operator is interacting with only one robot while cleaning.

A speculative design approach has been applied to this project, but the scope is delimited to only speculate around interaction modalities. Accordingly, we will still take the technical limitations of the system configuration software that are known today into consideration. Further, the currently established technical abilities and limitations of the future cleaning robots will be used as a starting point when creating speculative design concepts for interaction. In short, this means that we will create design concepts that builds on what is known about the system of cleaning robots today, but use speculative design to speculate freely around the interaction modalities used by the the key users.

2

Background

In this chapter, the background to this work is explained. The RoboClean Research Project that this master's thesis is a part of is described, the topic of hygiene in food production is brought forward as well as a review of related work.

2.1 RoboClean Research Project

The RoboClean Research Project is carried out in collaboration between ABB, Lagafors, RISE, Fraunhofer-Chalmers, and Örebro Universitet. It is partly funded by Formas, a Swedish research council for sustainable development, within the national research program for food. The goal is to investigate the possibilities for a system of collaborative, mobile robots to be cleaning in the food industry together with human workers. It started in 2019 and the project is planned to carry on until 2023. The purpose of introducing a system of robots in this context is to automate parts of the cleaning process and thereby improve the work environment for the cleaners, facilitate the cleaning and improve the quality in terms of cleanliness, food safety, repeatably, sustainability, and efficiency. The five stakeholders involved in this research project have different responsibilities and contribute with expertise within different areas. Below is a brief explanation of what each stakeholder brings to the table:

- **ABB Robotics** has expertise in robotics. In addition, they are also looking at a mobile platform and investigating how integration between a robot and a mobile platform could be done.
- **Örebro University** contributes with knowledge in mobile robotics, navigation, and vision.
- **Fraunhofer Chalmers** (FCC) are investigating the possibility to develop a program for path planning and cleaning optimization for the system of robots.
- **RISE** (Research Institutes of Sweden) contributes to this project with their competence in food production, hygiene, and cleaning.
- **Lagafors** is a company developing cleaning systems for the food industry and provides expertise in this area.

ABB means that a system of cleaning robots has the potential to make the work easier for the cleaners, and in continuation hopefully reduce the number of people working in this unfavorable work environment. Further, the implementation of cleaning robots could also enable standardization of the execution of certain cleaning tasks, ensure repeatability and improve efficiency. Another potential benefit of a system of cleaning robots is sustainability. Automation of cleaning methods opens up for applying water and chemicals in precise angles and patterns, thereby optimizing the cleaning and reducing the usage of water, energy, and chemicals. Altogether, the system has economical benefits in fewer man-hours, and lower costs when fewer chemicals, water, and energy are used.

However, ABB further states that a system of robots will not be able to manage all cleaning tasks on its own within the near future, due to the complex and uncertain environment as well as technical limitations and costs. That is why collaboration with humans is necessary to make a system of cleaning robots work in this environment.

User experience has been identified as crucial for the system of cleaning robots, but no work has yet been conducted within this area. Within this master's thesis, the goal is accordingly to gain an understanding of the context, the system of cleaning robots, and the key users, and thereby lay a foundation for continuous work with User Experience for the various key users interacting with the system of cleaning robots.

2.1.1 WML

Today's descriptions of how to clean are not adapted for robot programming use cases. A systematic way of describing the cleaning process and defining cleaning parameters is therefore needed. As a part of the RoboClean Research Project, a markup language for cleaning instructions is developed. The language is called Washdown Markup Language (WML) and defines how to clean an object based on a surface classification and the geometry of the object.

WML Classes

WML classes can best be described as a system for surface classifications. A WML class is defined based on the surface material, the type of dirt the surface has been in contact with, the kind of contact there is between this surface and the food that is produced, and the sensitivity of the surface. An example will be used to describe this further. A surface could be described as " A surface made of high density polyethylene, soiled with raw chicken, in direct contact with food, with a protection classification of IP66". Based on this information, this particular surface would be given a WML classification that responds to how this surface should be cleaned. A WML class in turn also contains data on the specific cleaning parameters to be used for this specific surface, such as what detergent to use, water temperature, pressure, spray distance, and spray angle.

WML Objects

An object consists of multiple surfaces, where each surface can have a different WML classification. A WML object is thus a CAD model of an object, where the different surfaces of the object have a WML class connected to them. Thereby, a WML object contains information on how to clean the different surfaces and what the surfaces look like. Based on this information an optimized way of cleaning an object can be derived.

2.1.2 RoboClean Configuration Software

The configuration of the robot system will be done using a software that is called RoboClean Configuration Software in this report. The initial version of this software is currently under development by FCC. FCC already have another software called Industrial Path Solutions, IPS used to plan for various kinds of production problems, and the RoboClean Configuration Software will be developed based on IPS.

Within the RoboClean Configuration Software, the system configurator will be able to build cleaning programs through cleaning path generation and optimization. The generation and optimization of a cleaning program would have to be done in several steps based on how the path planning works. However, no exact descriptions of the different steps included exist yet. Below is a description of how the software will function according to FCC, based on what is known today:

First, FCC describes how a geometric description of the curves the robot follows to clean a specific surface must be generated. This would be done based on a CAD model of the object, and how they are placed in the room, in combination with cleaning parameters for this object that are defined in the WML classes connected to the object's surfaces. Thereafter, the program calculates how the robot should follow the curve to optimize the process, taking additional parameters and limitations into account, such as the robot's range of motion and the angle towards the object.

2.2 Food Production & Hygiene

Efficient cleaning methods to ensure hygienic and safe food production is essential for the food industry. According to Lelieveld et al. [1, p. 447], there are strict requirements on hygiene and multiple regulations to ensure hygienic surfaces within food production. All surfaces in contact with food must be easily cleaned, kept in good condition, and disinfected when necessary. Thus, any surfaces in contact with food must be made of food grade materials, and the materials must also be resistant to the method of cleaning and cleaning agents to be used. Accordingly, developing efficient cleaning methods in line with industry regulations is of utmost interest.

During a visit to RISE Agrifood and Bioscience research center, the current methods for cleaning and challenges within this industry were explained and discussed. A researcher from RISE described how cleaning today is done manually and without clear guidelines of how the procedure is done in an effective way, and cleaning execution is therefore individual for each cleaner. The procedure is dependent on the cleaners' skills in terms of cleaning effectively and their ability to determine when the cleaning is sufficient.

At RISE they explained that there is no universal way of cleaning food plants due to a lot of factors. The food industry is complex, and factories vary in both equipment and layout. Furthermore, there are as previously stated also many variations in how the cleaning is executed by different cleaners. The cleaning process can thus look very different from case to case, but below is a general description of the different steps when cleaning food plants according to RISE:

1. Scratching off the dirt from the surface with a scraper
2. Rinsing off the surface with water
3. Application of cleaning agent foam
4. Let foam react during 10-15 minutes
5. Rinse off foam with water
6. Rinse off any remains with water

RISE further explained that food production often is partially or completely paused during the cleaning of the factory. This is done to minimize the risk of food contamination due to contact with dirt or any other unsanitary substances, and the daily thorough cleaning of food plants therefore typically occurs during late evening and night.

2.3 Related work

No system of cleaning robots that can be compared to the one investigated in the RoboClean Research Project exists today, but there are many examples of studies of robots used as cleaners in other contexts. Additionally, recent research has brought up other areas of relevance to this master's thesis, such as human-centered design and collaborative robots, design aspects in Human-Robot interaction, and designing for multiple user groups. A study of speculative design as a tool to envision human experiences in the future has also been carried out, as well as studies looking into the robot system integration process.

2.3.1 Cleaning Robot Systems

Industrial cleaning robots can be found in several contexts within the literature, but in general, most academic studies focus on the robot and its tasks and not the human interaction with it.

However, Bitonneau et al.[25] studied a cleaning system for a pyrotechnic tank to replace the manual cleaning which is physically demanding, a situation similar to the one in food plants. Further, they propose a human-centered approach when creating collaborative industrial robots. They also highlight how the involvement of actual users in a human-centered design process is essential. It is explained how expert insight from users and knowledge of the context in which the robot will operate can improve the final design solution and facilitate the adaption of the system to the specific context and its users.

Yin et al.[10, pp. 1–3] describe how cleaning in food courts suffers from workforce shortage due to long working hours, low wages, and a general unwillingness to work as a cleaner, issues similar to the problems within cleaning in the food plants. In an effort to find a solution to these issues, a Human Support Robot is introduced. As a part of this solution, a system to detect litter and plan the path for cleaning is proposed. More in detail, the supportive robot can perform inspections of cleanliness and clean the tables through the implementation of deep learning and a framework for planning. Experimental results show that the Human Support Robot system detects food litter with high detection accuracy and cleans tables within a reasonable time [10, p. 17].

Alike the food plant cleaning context, building facade cleaning is an area where robots have the potential to tackle issues in the work environment, promote sustainability, and reduce costs according to Gambao and Hernando [11, p. 406]. To improve in these areas, a system of robots has been developed to perform the cleaning task semi-automatically. The robot performs most tasks but with assistance from humans, similar to the system of cleaning robots researched in the RoboClean Research Project. A significant difference is however that the facade cleaning robot had no collaborative applications, and interaction with this robot only took place remotely with the operator located on ground level while the robot works on a facade. Testing of this system of robots cleaning building facades proved successful, as the work was done with higher efficiency and reduced cost [11, p. 411].

2.3.2 Human Centered Design & Collaborative Robots

Prati et al. [13] state that there has been a gap between robotics and interaction design for long. While the experts developing collaborative robots usually have deep technological knowledge, the importance of interaction design is often foreseen. Consideration of human factors and human interaction throughout the design process of collaborative robots have therefore in general been lacking.

Attempting to bridge the gap between interaction design and collaborative robots, Prati et al.[13] discuss how tools and principles can be applied when designing and developing solutions. Methodological principles and practical tools are proposed to assist designers, from the analysis of users' needs to the creation of a design. A specific toolbox to collect data about user requirements is proposed followed by user journeys to describe the journey and interaction.

In another paper, Prati et al.[12] further discuss how most research within the field of Human-Robot Collaboration is focusing on the technology and fails to cover aspects of human-centered design. They see a need of considering human factors, more specifically the User Experience in Human-Robot Interaction. More in detail, they promote mapping the interaction between human and robot by applying tools from User Experience design in order to successfully identify requirements and design aspects of importance for Human-Robot Interaction. Further, their approach is about applying these methods in addition to the focus on technological details to get a holistic view including aspects of human-centered design. The results from the study imply that the inclusion of new methods from the field of User Experience design contributes to a successful identification of user needs and promotes improved Human-Robot Interaction.

In a paper by Chowdhury et al. [14] User Experience Driven Design is investigated in relation to Human-Robot Interaction between humans and industrial collaborative robots. A preliminary study to explore the context was conducted, followed by a study designed to gain an understanding of the User Experience of programming and collaborating with a collaborative robot. The study resulted in four User Experience goals for Human-Robot Interaction with collaborative robots. These are *Accomplishment*, *Safety and Trust*, *Fellowship and Sympathy* and *Inspiration*.

The first goal by Chowdhury et al. [14] is *Accomplishment* and it is related to the motivation of the user. The study showed that users are more motivated to interact with a collaborative robot if there is intrinsic motivation. The satisfaction of having completed a task serves as this intrinsic motivation. The second goal *Safety and Trust* relates to how safe the user feels when working together with the robot. This goal is crucial, and already very common to consider in Human-Robot Interaction with collaborative robots. The third goal *Fellowship and Sympathy* treats the creation of an emotional and social bond between human and robot that can reduce anxiety and promote collaboration. The fourth and final goal *Inspiration* has to do with reducing workers' negative feelings towards working with a collaborative robot by inspiring them to solve issues. When successfully solving an issue, participants in the study expressed feelings of inspiration and pride.

In the development of collaborative robots for industrial work systems, Kadir et al. [9, pp. 608–609] have identified five key design factors. These key design factors are: *Understanding Existing Processes*, *Clear Division of Tasks*, *Visualization of Robot's Path and Workspace*, *Standardized Operating Procedures*, and *Develop Systematic Quality Control*.

To enable a successful implementation of collaborative robots in the future Kadir et al. [9, pp. 608–609] argue that there is a need for an in-depth understanding of existing work systems and a plan for the division of work, hence the first key design factor *Understanding Existing Processes*. The next key design factor described is *Clear Division of Tasks*. How work tasks are divided between human workers and robots should be decided based on the capabilities/skills required to complete a certain task. Repetitive tasks are suitable for robots, while humans are superior at tasks that require flexibility and creativity. *Visualization of Robot's Path and Workspace* concerns predictability and visualization of how robots can move in a space. This visualization can make human workers feel safer in proximity to collaborative robots, and in addition, reduce the risk of collision. The next design key factor is *Standardized Operating Procedures*. With standardized procedures implementation of improvements in efficiency and sustainability becomes easier, and in addition, it can enhance consistency in output, efficiency, and workers' rate of learning the system. The last key design factor is *Develop Systematic Quality Control*, which is the need of developing procedures for quality control as this can reduce defects, production stops, inefficiency, and frustration.

2.3.3 Design Aspects in Human-Robot Interaction

A framework with four different categories of robot characteristics is developed in a study discussing cultural aspects of domestic robots by Lee et al [17]. The categories are similar to the ones mentioned as potentially important for robot acceptance described in section 2.3.6, robot function, robot social capability, and robot appearance. These four categories for robot characteristics are: *Look and feel*, *Interaction mode*, *Social roles*, and *Desired tasks*.

The *look and feel* category includes the main design concept and form of the robot. For example, its shape which can vary from abstract to anthropomorphic, its gender, and the materials and size of the robot. *Interaction mode* includes the way the human interacts with the robot, for example, speech, gesture, or a graphical interface. Additionally, the level of robot autonomy and user control is also part of the interaction mode. The *social role* refers to the social position of a robot. It relates to sociability, the robot's ability to behave according to socially accepted norms. *Desired tasks* concerns the expectations regarding the robot's function and the tasks it could handle [17].

Another study conducted by Wilkinson et al. [18] presents a set of design principles for user interfaces of an assistive robot where users without robot expertise are to interact with the system of robots in an open environment. With these three design principles, *Understandable*, *Reliable*, and *Accessible*, Wilkinson et al. [18] aim to describe how a user interface for such interaction should be.

Understandable, A user interface for a robot system designed for users without significant robot experience must provide sufficient feedback. It should be possible to operate the system with minimal instructions. In addition, the current state of the system should be communicated to the user at all times. *Reliable* points out that since user errors, as well as system errors, are likely to occur at some point, the robot must be able to handle such errors systematically. Lastly, *Accessible* emphasizes that the user interface should be designed in a way that enables people with different physical and cognitive abilities as well as with the different levels of experience with robots to interact with it. A user interface that offers different access methods is thus promoted.

2.3.4 User Roles in Human-Robot Collaboration

Robots will continue to advance and be able to perform increasingly complex tasks in a wide variety of contexts, a prognosis that makes some think robots might ultimately replace human workers. However, that is not the case according to Bragança et al.[15, pp. 641–650]. They predict that robots will take on the role of assistants, and human workers will take the lead as humans are still superior when it comes to all tasks that require flexibility, nuanced reasoning, and creativity. Robots on the other hand will perform tasks where a machine is superior to a human, for example when high force, speed, and precision are needed or when handling big databases. Introducing collaborative robots in the industry is not a competition to human workers, as robots and humans will play different roles. Rather, it is fostering a successful human-robot partnership.

Schmidbauera et al. [16, pp. 399–400] describes four different kinds of users in relation to a collaborative robots (cobots) based on their levels of interaction: the *Bystander*, the *Modifier*, the *Programmer*, and the *Integrator*. The *Bystander* only performs basic interaction with the cobot and needs to safely interact and be co-located with the cobot. They need to know the state of the system and to be able to start, pause and stop the machine. The *Modifier* performs basic modifications of the cobot control programs, for example changing variable values. The *Programmer* creates or modifies the cobot control programs. For example, if the cobot has a new tool or needs to operate new tasks. The *Integrator* integrates the cobot work system into an existing environment. For example, the integrator implements communication to peripheral equipment.

In general, the user-centered approach that is breaking new ground regarding collaborative robots is focused on the end user collaborating with the robot. A need to expand the scope to focus on all user groups related to the collaborative robot systems has thereby been identified.

2.3.5 Designing for Multiple User Groups

Renaud et al. [19] describe how products generally are used by multiple user groups in different ways, and the needs of these users are often contradictory. They argue that understanding different kinds of users, their goals and their way of using the product thus is important in creating better designs and User Experiences. As a method to map the needs of different user groups and identify possible contradictions, the authors propose a functional analysis addressing the different users, their usage of the product, and the product life cycle. The application of the functional analysis method is demonstrated with a case studying a car seat for babies.

In their study, Wasson et al. [20, pp. 236, 260–261] focus on a large scale computing system that is intended for multiple, diverse user groups where members of the different user groups use the computing system for completely different purposes. The different user groups are also likely to face different technological capabilities and constraints. They argue for the importance of ethnographic research in order to understand the different needs, practices, and constraints of different user groups, to ensure that the system responds to them. Further, they highlight that computing systems are unlikely to live up to their potential usefulness without user research. Additionally, they argue for their approach to be useful in other contexts as well.

According to Jul et al., [21, p. 1] traditional design practices tend to fall short in domains that involve multiple user groups. Literature on user-centered design occasionally urges for considering the possibility of a need for multiple user groups, but the methodologies tend to only imply one group of users. They propose an analysis of user groups to be added to traditional user-centered design, which includes seven steps: [21, p. 6]

1. Identify relevant groups
2. Identify goals for each group
3. Establish criteria for success for each group
4. Determine the relationships between groups
5. Identify potential conflicts between the goals and criteria of the groups
6. Resolve the conflicts between the groups
7. Establish criteria for success for a multiple-user group design

The groups and their goals, as well as criteria for success, can be established using traditional user-centered design techniques and methodologies [21, p. 6].

Jul et al. [21, p. 2] classify the relationships between different groups as either independent, result-dependent, or process-dependent. Where the independent relationship includes user groups whose work is affected by the software by one group in no way depends on the work of the other. A relationship is Result-dependent if one group is dependent on the outcome of the work of the other group. In a process-dependent relationship, the work of one group depends on the way in which another group performs its work.

Some of the relationships between the different groups might be immediately obvious while others are more subtle. Techniques to understand organizations are described to be useful in uncovering result-dependencies. Once result-dependencies are found, those are checked for process-dependencies [21, p. 7]. To identify and resolve conflicts Jul et al. [21, p. 7] argue that participatory design is a suitable technique. To establish the overall criteria, the criteria for each group must first be prioritized, and then merged with criteria from the other groups.

2.3.6 User Attitudes towards Human-Robot Interaction

Technological advancements have enabled robots to enter new markets and applications of robots in new settings, and robots keep encountering new user groups according to Beer et al. [26]. Resulting from this, robots will not only be in contact with formally trained users but also interact with users who have little or no previous experience with robots. The acceptance of the robot by the human is a crucial factor for successful human-robot interdependence [27, p. 709].

Despite this, Beer et al. [26, p. 4] state that there is a lack of theoretical models developed specifically to understand and explain the acceptance of robotics. On the contrary, there are numerous models to study the acceptance of technologies, such as the *Unified Theory of Acceptance and Use of Technology Model*, the *Technology Acceptance Model* and *Use of Technology Model*. These models are unable to address robots in particular and do not raise relevant robot-specific questions, but treat the overall acceptance of technology. Thus, factors that might affect the acceptance of a robot can be derived from these models, and the following aspects have been identified as potentially significant: *Robot function*, level of autonomy, user control, and user interface. *Robot social capability*, social intelligence, nonverbal social cues, and emotions.*Robot appearance*, shape and form, semiotics, and level of anthropomorphism.

Elprama, Jewell, Jacobs, El Makrini, and Vanderborght [28] notifies that little attention has been paid to the attitudes and needs of the actual potential users of collaborative robots. Therefore a study to explore those attitudes and needs was conducted. The study included interviews where the factory workers were interacting with a robot. From this, they found that all workers were concerned that the robot could take (their) jobs. Nevertheless, they also saw the potential of the robot to lighten their mental and physical workload. Additionally, the factory workers did not express concerns related to safety when collaborating with robots.

2.3.7 Human-Robot Interaction & Perceived Control

Zafari and Koeszegi [29, pp. 2071–2072 & 2078] found that the robots´ improved capabilities to act autonomously or make decisions, in general, resulted in a more negative attitude toward robots. To deepen the understanding of what it is that influences peoples' behavior and attitudes toward robots, they investigated the effect of perceived control. Their study shows that humans perceiving a low level of control when collaborating with a robot with a high level of attributed agency is associated with a negative attitude towards the robot. Perceived control is found to mitigate negative attitudes towards robots and foster social relationships between humans and robots.

Similarly, a study by Akalin, Kristoffersson, and Loutfi [30, p. 2] shows a correlation between control, trust, and perceived control. When participants in their study felt in control, they were also comfortable and trusted the robot.

2.3.8 Human-Robot Interaction & Perceived Safety

Bragança et al. [15, pp. 641–650] describe how robots for safety reasons have been physically separated from humans within the industry historically. Now, the emergence of collaborative robots has started to change this spatial division, which has given rise to a need for alternative ways of working with safety. New strategies must be developed to ensure safety for humans working in proximity to or/and in collaboration with robots. In contexts where humans and robots collaborate, the planning of tasks must be done in a careful and exact manner. When planning work and assigning tasks to humans and/or robots, the individual limitations of each part must be taken into consideration. In addition, avoidance strategies should be implemented. For example, the ability to detect objects and movements prevents collision with humans as well as objects in the surrounding.

Safety is critical when designing for interaction between robots and humans as stated by Bartneck et al.[31, p. 76]. The abilities and functionalities of the robot are obvious aspects of importance when studying safety around collaborative robots, but in addition to this, the humans perceived safety and User Experience from interacting with the robot is of great significance. Aspects of perceived safety cover how safe humans feel when working in proximity to or in collaboration with a robot. To achieve acceptance of a robot from industry workers and collaborators, perceived safety is crucial.

Akalin, Kristoffersson, and Loutfi [30, p. 15] also argue that perceived safety is an important factor in HRI. In their work, they identified six important factors that influence the perceived safety in a situation when humans interact with robots. These factors are *comfort*, *experience/familiarity, predictability*, *sense of control*, *transparency*, and *trust*.

A predictable behavior and consistency in the behavior of robots is of importance for the perceived safety in HRI [30, pp. 6 & 13][32, p. 19]. If the robot's intentions are clear to humans it enhances the perceived safety. Thereby consistent robot behavior has the potential of enhancing the perceived safety.

2.3.9 Speculative Design in Research

In a study by Sengupta and Kant [24], they identified a need to focus on both human experience and technological systems when designing for the future setting of industry 5.0. To achieve this, they applied a speculative design approach to comprehend human experience in the next generation of work systems. They took into account the need for humans and technologies to work together as well as the perspective of humans in technological systems. In their work, they created a future scenario that was used for speculative enactments and based on this derived design recommendations for the futuristic design of human work experience.

Luria, et al. [33] conducted ethnographic investigations as well as developed speculative design concepts of Human-Robot Interaction related to the destruction of robots. They exemplify speculative uses of destruction in HRI to bring a fresh perspective on alternative interactions with robots.

Auger [34] has conducted work in the area of how robots can become domestic products by adapting speculative design. With the use of various design projects he shows on alternative approaches to robots, and how those can contribute with new perspectives on research and development of technical products. In another study relating to robots as domestic products, Auger [6] discuss how speculative design can be used to present probable technological applications in the near future.

2.3.10 Robot System Programming & Integration

Wilson [35] describes robot systems and different aspects of successful system integration in industrial settings, primarily focusing on manufacturing. Further, Wilson [35, p. 186] highlights the fact that a robot, despite its many benefits and capabilities, cannot do much on its own. A robot only makes a part of a complete system solution, and other elements in the system must provide the robot with the capability to perform the tasks that are required. Humans programming robots is one example of how the system of robots can be provided with this capability.

For ease of use and to modify existing execution programs for collaborative robots Schmidbauera et al. [16, p. 398] sees a need for intuitive interfaces. The increasing diversity in the personnel interacting with the robot also requires an approach to robot programming that is obtainable to those users.

Rossano et al. [22, p. 1119] sees a need for simplifying the programming tasks in order for the owner of a robot to create or edit the robot program. The identified guidelines for developing and assessing an "ease of use" programming approach. The guidelines include a user-centered approach where they see a need of considering the target user and the core scope of their programs. Including identifying the target users' personas and paying careful attention to their experience with programming and robotics. Additionally, they highlight the importance of considering how simplified programming affects the advanced users to ensure their work is not hindered. In general, they argue for an understanding of the users of the system, the context of the programs they need to write, and their overall goals. All phases of programming need to be taken into consideration, including editing, tuning, debugging, and the physical nature of robot programming.

The International Federation of Robotics [23, pp. 3–4] is however discussing how the roles of system integrators and experts in robotics have changed in recent years. As programming interfaces are becoming more intuitive and easy to understand, the process of integrating robots is in turn becoming more intuitive. Depending on the complexity of the system of robots that is to be implemented, the involvement of system integration experts may vary.

Collaborative robots, or cobots, are in general smaller, lighter, and easier to move according to The International Federation of Robotics [23, pp. 3–4]. With the development of collaborative robots, a new market segment of end-users with limited or no knowledge of robotics and automation is emerging. In addition, this user group has generally no intention to become robotics and automation experts, which introduces new challenges when it comes to the integration and maintenance of collaborative robot systems. Grippers hold and sensors are examples of technological tools developed to enable end-users to perform more actions.

3

Theory

This chapter describes the fundamentals of interaction design, the area of Human-Robot Interaction, and theory related to this project.

3.1 Interaction Design

According to Sharp et al. [4, p. 9] interaction design is defined as the design of interactive products that support peoples' ways of working, communicating, and interacting. Apart from interaction design, there are a lot of other terms used to describe the development of interactive products. User Experience (UX) is a common example, a notion emphasizing the experience a product is designed for evoking, and a concept that is central in interaction design. Interaction design is however generally used as the overarching term, thus including User Experience. Nevertheless, these terms are closely related and can be used interchangeably according to Sharp [4, p. 9].

Sharp et al.[4, pp. 15–16] further describes how the users are central in interaction design. Understanding a specific user group and their context is the key to understanding how to design for the requirements and needs of users in this context as well as for a good User Experience. By collecting knowledge about people and their behaviors in a certain context, incorrect preconceptions and faulty assumptions can be prevented.

3.2 User Experience

User Experience (UX) is a design practice with a focus on creating experiences when using or interacting with a design, typically with the aim of being easy to use and satisfying to the user according to Nichols and Chesnut [3, p. 8]. The design practice puts the user at the center of all considerations to ensure that the eventual experience provides an intuitive, helpful, and enjoyable interaction. According to Benyon [36, pp. 5, 22], the practice of UX is concerned with developing high-quality interactive systems, products, and services, which fit into peoples' lives. This is in general done with a human-centered design approach.

Alenljug et al. [37, pp. 5–6] describe how users' expectations and demands go beyond utility, usability, and acceptance. A product that is suitable for its purpose, easy to use, and fits into its intended context are basic requirements, a positive and great experience when interacting with the product is now a demand. A good User Experience is not built into the product itself but is an outcome of the interaction, which depends on the internal state of the user, the quality and attributes of the product, and the particular situation. UX is an umbrella term that embraces users' emotions, beliefs, preferences, perceptions, and accomplishments, which emerge before, during, and after the use of a product in a certain situation. Chu [8] describes how the context prescribe peoples' need and how the User Experience of a product is highly dependent on the context in which they are used. Law et al. [38, p. 2397] highlights that one cannot design User Experience, but design *for* User Experience.

3.3 Human Centered & User Centered Design

The ISO standard 9241-210:2019 describes Human Centered Design as "an approach to interactive systems development that aims to make systems usable and useful by focusing on the users, their needs and requirements, and by applying human factors/ergonomics, and usability knowledge and techniques" [39]. Human Centered Design has proven to increase the efficiency of operations and user productivity, improve user understanding of systems and products, and lead to overall increased Usability and User Experience. The Human Centered Design Approach builds on the following principles [39]:

1. Understanding the users, their tasks and the context is fundamental.
2. Users are involved during the entire design process.
3. Evaluations with users drive the refinement of the design.
4. The design process is iterative.
5. User experience is central.
6. A multidisciplinary approach is taken.

User Centered Design is a design approach designing for users by involving users in the process [40, p. 105] [41, p. 1]. However, it is not the users themselves that are designing, even though they engage in design activities as participants of design research. The User Centered Design is rather a collaboration between designers. An important part of User Centered Design is to profile users, define their behaviors and preferences, and base the design decisions on this [41, p. 1].

3.4 Usability

In the ISO standard 9241-11:2018 Usability is defined as the "extent to which a system, product or service can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use" [42]. Effectiveness relates to the accuracy and completeness with which users achieve specified goals. Efficiency concerns the resources used in relation to the results achieved, which includes for example time, human, effort, costs, and materials. Satisfaction is the extent to which the user's needs and expectations are met when using a system, product, or service. The context of use includes a combination of users, goals and tasks, resources, and environment.

3.5 Speculative Design

According to Auger [7], speculative design is a practice that enables speculations about technologies and design concepts. There are two different kinds of speculative design separated by the aspect of time: A speculative design either describes a possible future or an alternative contemporary present. Within speculative design, the designer can step aside from normative design processes. Speculative design stretches the boundaries of reality and involves fiction to enable discussions about design concepts, unrestrained by high-technological expertise setting the limits for what is possible today. Auger [6] further talks about speculative design as a tool for dreaming, challenging, and debating, intended to appeal to a broad and diverse group of people. From designers, engineers, and scientists, to customers and users of technical products and services.

According to Malpass' [5] definition of speculative design, it is a design practice exploring possible futures with a focus on emerging technologies and science. Designers often work together with scientists and make use of scientific practices, with the aim of making science and possible future impact on society perceptible to a wider audience through speculative design. Auger [6] describes how speculative design effectively introduces the complexities of human character into scientific research. Malpass [5] further mentions fields like biotechnology, synthetic biology, nanotechnology, and robotics as possible design spaces for a designer to operate in.

Mitrovic et al. [43] describe how speculative design has moved from critiquing or questioning possible futures toward being used as a method to innovate. Where designers work together with scientists and engineers to give shape to a possible future.

Auger [7] argues that it remains important for speculative design concepts to be rooted in science and not go too far away from reality. By iteratively creating speculative design concepts based on logical reasoning about emerging technologies and anchored in the complex needs of actual users, the speculative design results become stronger. Auger [7] further describes the need for a bridge in a speculative design concept, something familiar to anchor the fictional aspects of the design to the contemporary world and make the speculation relatable. Similarly, Auger [6] describes how an audience fails to relate to speculative designs that stray too far in the future or are too extreme. The design speculations require a connection between the audience and the concept in order to be relatable and engaging.

A method for speculative design described by Auger [7] is called the ecological approach. This method concerns speculative design for a certain, known context. When using this method, the designer must know the context and work with the requirements the specific context sets for the design, and this will in turn create a bridge to anchor the speculative design in a relatable reality.

According to Malpass [5], narratives can provide a vivid description of how a design concept is used by a specific user in a certain context. This enables users without significant technical expertise or design experience to emphasize and create an understanding of a futuristic design concept. Malpass [5] thus argues that narration can be a powerful tool and further states that speculative designs often require a narrative to support understanding of the design concept in detail and its use. According to Malpass [5] narratives can be told through scenarios and visualizations. Media such as photography and video can also be useful to describe a design concept in a specific context.

3.6 What Is a Robot?

In the ISO-standard 8373:2021 [44] a robot is defined as *"a programmed actuated mechanism with a degree of autonomy to perform locomotion, manipulation or positioning"* [44].

The International Federation of Robotic describes a robot as "an actuated mechanism programmable in two or more axes with a degree of autonomy, moving within its environment, to perform intended tasks"[45]. Where autonomy refers to the ability to perform intended tasks based on the current state and sensing, without human intervention. The level of autonomy can vary widely, from a simple robot performing repetitive manufacturing tasks to the *Curiosity robot* exploring Mars [46, p. 205].

3.7 Categorization of Robots

There are many different types of robots serving different purposes. To make a distinction between these, robots are usually categorized as either industrial robots or service robots.

An industrial robot is defined as an "automatically controlled, reprogrammable multipurpose manipulator", programmable in three or more axes, which can be either fixed in place or fixed to a mobile platform for use in automation applications in an industrial environment" [44].

A service robot is defined as a "robot in personal use or professional use that performs useful tasks for humans or equipment" [44]. The International Federation of Robotics [45] defines service robots as robots performing useful tasks for humans or equipment that is not an industrial automation application.

However, the development of robotics has started to step away from the fully automated manufacturing process towards processes where humans and robots work closely together at the same place and time [27, p. 709].

A collaborative robot, or a cobot, is a robot working side by side with a human. They perform sequential tasks as well as parallel ones [47, p. 1]. Cobot systems are intended for collaborative operations, with concurrent execution of tasks by human(s) and robot(s) in a collaborative workplace. The system is not collaborative by itself, rather, the collaborative nature arises from the design of the application and the interaction. A system of collaborative robots generally includes a robot and a graphical user interface, which is used by humans to program the robot to do a specific task [48, p. 1].

3.8 Human–Robot Interaction

Human-Robot Interaction (HRI) is a research field focusing on understanding, designing, and evaluating robotic systems for use by or in collaboration with humans [44]. At first, HRI mainly concerned the remote operation of industrial robots in factories, but today after decades of technological advancements in the robotics field it goes far beyond that [49, p. 2]. Progress in fields like programming, perception, and reasoning has made autonomous robot behaviors possible, paving the way for new areas of HRI.

HRI requires communication between the two parts, and this communication can take different forms. In general, the means of communication between human and robot depends on whether they are in proximity to each other or not. Based on this, the interaction is generally separated into two different categories: Remote interaction and Proximate interaction. Remote interaction takes place when the human and robot are not co-located. When the human and robot are co-located, the interaction is proximate[50].

The level of autonomy of a robot regulates what tasks the robot can perform independently. Furthermore, the level of autonomy also impacts user interaction, that is, to what extent the robot is interactive and how the interaction takes place. Taking the level of robot autonomy into consideration is accordingly of great importance within the field of robot-human interaction[51].

3.8.1 Forms of HRI

The different forms of HRI are often not distinguished in industry and international standards [2, pp. 103–104]. Nevertheless, scientific publications distinguish between coexistence, cooperation, and collaboration. Coexistence is the weakest form of interaction where it is limited to shared time and space. In cooperative work, the responsibility is divided between the human and the robot who are conducting different tasks to reach a common goal. Within the cooperation, the human and robot do not depend on each other due to the clear division of labor. In the collaborative work, the human and robot work together and are in direct contact with each other and the distribution of subtasks takes place continuously. The creation and use of synergies characterize the collaboration.

Instead of talking about forms of interaction, Sholtz [49, pp. 4–6] describes five different roles a user can have when interacting with a robot. The roles described by Sholtz are called supervisor, operator, mechanic, bystander, and teammate, which have similarities to the coexistence, cooperation, and collaboration described by Müller-Abdelrazeq et al. [2, pp. 103–104]. If the user has the role of a supervisor, the user monitors the robot and controls it remotely. If the user is an operator instead, this user makes adjustments to the robot's internal control mechanisms. While the operator programs the robot, the mechanic role takes care of adjustments of mechanical components and other physical components. A bystander is a user that co-exists in the same environment as the robot but does not actively interact with it. However, users in this role still need to understand the robot's behavior to some extent. For example, a human standing in the way of a robot vacuum cleaner should understand if the robot will sense the human's presence and change the route, or if the human must step aside. The teammate is the final user role, a human that collaborates with a robot to complete a task [49, pp. 4–6].

4

Methods

This chapter contains an introduction to research through design and the interaction design process. Further, the methods used in this master thesis are listed here. The order in which the methods are listed has been arranged according to the different stages of the interaction design process. However, the design phases are overarching and the design process is iterative. Thus, the categorization of a method into one of the design phases here does not mean that it has been carried out exclusively during this phase.

4.1 Research Through Design

In an essay by Gaver [52], different perspectives on design research are explored. Gaver claims that we need to modify our expectations on verifiable perpetual theories when conducting research through design. Despite the often improvised and unexplored character of design, conceptual design theories have nevertheless proven to foster and inspire successful research. Gave further argues that the focus should be on pursuing research by application of appropriate methods and theory for the task, rather than getting limited by strict, traditional frameworks trying to distinguish between what is science and what is not.

Gaver [52] further discusses how design research can benefit from deviation from norms for what a research process or outcome should look like. Design research can build on results from other studies, but research results from other studies can also be overthrown. Design research can even establish completely new and independent research alternatives. A similar approach should be taken on design methodology and execution. It can follow or build on previously established frameworks, but these can also be questioned and subverted.

4.2 The Interaction Design Process

The Double Diamond is a framework by the Design Council [53] describing the design process. The model consists of four phases: *Discover*, *Define*, *Develop*, and *Deliver*. The different stages of the interaction design process are intertwined, but a brief description of each follows below.

The first phase *Discover* is according to Sharp et al. [4, p. 50] focused on discovering requirements by exploring the problem space and creating an understanding of the context and the user. The interaction designer(s) is also starting to define what is to be designed based on the findings during this stage. Application of data gathering methods such as interviews and observations, and data analysis are commonly used in this phase according to Sharp et al. [4, p. 50]. During the second phase *Define*, Sharp et al. [4, pp. 38–50] describes how ideas are starting to form. Different alternatives are considered at all times. Suggestions on interaction design solutions are first done at a conceptual level, and later on, refined. This stage is followed by *Develop*, a phase where Sharp et al. [4, pp. 38–50] describes how the designer(s) starts to explore the behavior, look and feel of the possible interaction design solutions. Prototypes are first created in low fidelity and subsequently refined into higher fidelity. Evaluations with users are continuously conducted where different kinds of interaction with the prototypes are tested. *Deliver* is the final stage according to Sharp et al. [4, pp. 38–50], and this is where the result is refined further. Ultimately, the final design is presented and delivered.

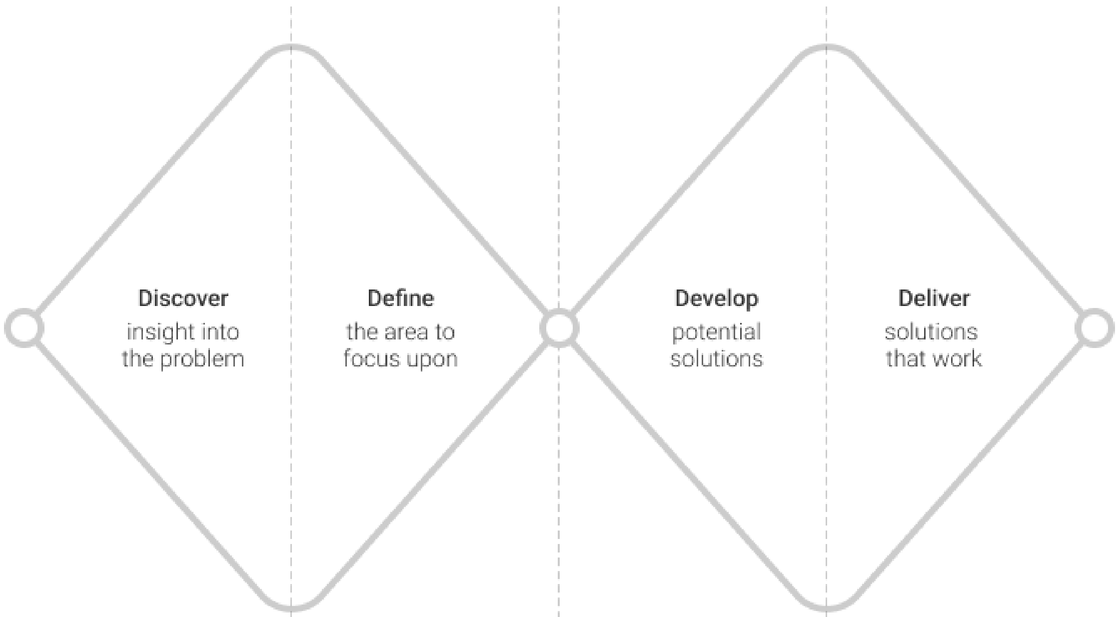


Figure 4.1: The Double Diamond

4.3 Methods for Discover

Sharp et al. [4, pp. 259–260] explains that data gathering is a central part of the phase Discover. It is important to collect sufficient and accurate data to bring value to the project. Data can be quantitative or qualitative and can consist of, for example, numbers, descriptions, comments, photos, sketches, or almost anything that contributes to an understanding of user needs and user behavior. This section describes the methods used in this project to gather and analyze data with the aim of understanding the context, the users, and their needs.

4.3.1 Observation

As described by Baker [54, p. 173] observation studies include studying and understanding people within their neutral environment. When observing the researcher should pay attention to the physical space and objects, the people present and connected with the situation, and their activities, behaviors, and emotions, as well as the events and the sequencing over time [55, pp. 36–38].

Baker [54, p. 183] and Ciesielska et al. [55, p. 41] describes how the observer often takes notes while making an observation. For successful note-taking, the observer should note things down right away to avoid subsequent reinterpretation of what happened. The note shall also include details, such as initial impressions, behaviors, sounds, etc. Nonetheless, it is not possible to observe everything at once, and therefore it is important to decide on a main goal for the observation to focus on.

According to Baker [54, pp. 173–177], the observer can take a range of roles in the observation. Nonparticipation, Complete Observer, Observer-as-Participant, Participant-as-Observer, and Complete Participation are a few of them. *Nonparticipation* involves no level of involvement with the insiders that are observed. The observer is not present in the scene but observes from an entirely different environment. The role has the advantage of being effective for some studies but does in general not allow for an in-depth understanding of people's behavior [54, p. 174]. In the role as a *complete observer*, the observer is present in the space but does not participate in the tasks or interact with the insider to any great extent. Thereby, the role is only to listen and observe [54, p. 174]. The role as *Observer-as-Participant* includes more observation than participation. The observer is slightly involved with the insiders and is mostly involved in observing but may also conduct short interviews [54, p. 175]. When taking the role *Participant-as-Observer*, Baker [54, p. 177] describes how the observer is more involved with the central activities but is not fully a member of the insiders. *Complete Participation* is the ultimate level of involvement where the observer studies a group that he/she is already a member of [54, p. 177].

4.3.2 Interview

An interview is a conversation where an interviewer asks questions to an interviewee, according to Sharp et al. [4, p. 269]. Interviews are generally used for gathering qualitative data. An interview can be shaped in different ways in order to fulfill its aim. Below are three different ways of conducting interviews described.

During a *structured interview*, the interviewer asks predetermined questions. The questions are the same, worded the same, and are asked in the same order to each participant so that the study is standardized. Structured interviews are useful when goals are clearly understood and specific questions can be identified. Those questions are often closed questions, meaning that they require an answer from a predetermined set of alternatives [4, p. 269].

A *semi-structured interview* is, according to Sharp et al. [4, pp. 269–270], an interview where both open and closed questions are asked. The purpose of semi-structured interviews is to make room for probing and exploring the topic further, but still, make it possible to replicate the interview. The interviewer follows a prepared script asking questions and then probes to get deeper into the topic. Probes are useful to get the interviewee to talk more and share more information on a topic. However, it is of great importance when asking questions and probing that the interviewer does not bias the interview by making formulations that indicate assumptions. Questions should be formulated without indicating any expected answer.

Unstructured interviews are exploratory and can be described as a conversation around a particular topic according to Sharp et al. [4, p. 269]. The questions are generally open, making it possible to steer the interview in the desired direction. Yet, the interviewer needs a plan for the interview to ensure the desired topics are covered. The interviews have the potential of bringing up topics or issues that the interviewer had not thought of before and often result in rich insights.

Questionnaires are widely used to collect demographic data and user´s opinions. Alike interviews they can have both closed or open-ended questions. A questionnaire can be distributed to a big number of participants without requiring big resources. Therefor, questionnaires are useful for getting answers to specific questions from a large group of people [4, pp. 278–279]. However, to explore a new field and gain a deep understanding of users and their needs interviews have been found to serve our purpose better as it allows for probing to dig deeper into the topics brought up.

4.3.3 Thematic Analysis

Thematic analysis is, as described by Braun and Clarke [56, pp. 79–80] a term used to describe methods for sorting and analyzing qualitative data. With thematic analysis, researchers organize data in relevant categories and identify themes or patterns in a data collection. Braun and Clarke [56, pp. 86–93] divide the process of doing thematic analysis into six steps.

1. The researchers look into the data collected and read through all the material to get familiar with it.
2. A number of initial codes are created based on the findings and the data is sorted into these categories accordingly.
3. Potential themes are formed from the codes, and data is sorted into these themes.
4. The categorization into themes is reviewed and compared to the codes from step two and the themes from step three to ensure that these match.
5. Each theme is refined and further specified and the different themes are also given names in this step.
6. The organization of data into themes is summarized by for example including this in a written report, and insights and parallels to the research questions can be drawn.

4.3.4 Affinity Diagram

Sharp et. al. [4] suggests that Affinity Diagrams is a method that can be used when carrying out a thematic analysis. Affinity diagrams can be executed physically or digitally, and are built by adding notes with data one by one onto a blank wall. The notes are clustered together with others that they are related to, and a cluster of notes with qualitative data is thus gradually created.

4.4 Methods for Define

During the define phase, the problem is gradually defined and ideas are starting to form [4, pp. 38–50]. The following section described methods used to define the users and their current work environment as well as what demands this puts on a design in this context.

4.4.1 Personas

A persona is, according to Sharp et al. [4, pp. 403–407] a description portraying a typical intended user. This description usually includes a name, an image, and a description of some personal characteristics. A persona also has personal goals that relate to the project and the product that is being developed. The purpose of personas is to serve as a tool for decision making in the design process, as well as a reminder of the real-world users that will be using the product under development. Personas should be realistic and the characteristics of personas should be anchored in attributes and attitudes from real users identified from data gathering. Usually, a few different personas are developed for a project, with one primary persona and additional supportive personas.

4.4.2 Scenarios

Sharp et al. [4, pp. 408–410] describes scenarios as a method to describe a specific situation that is relevant for a design project. It is a narrative describing user activities in context, and it can bring up aspects like user needs, expectations, and requirements. With scenarios, designers can communicate a situation efficiently to other designers as well as non-designers and discuss different aspects of the scenario. Scenarios are used to describe the current user situation as well as situations in the future where the product under development is used.

4.4.3 Requirements List

A requirement is a statement that specifies what is expected from an intended product and how the product will perform according to Sharp et al. [4, pp. 387–388]. The goal is to extract user needs from data gatherings and identify and capture these into clearly defined requirements. Additionally, it is preferable to also specify measurable criteria for each requirement. This is to enable comparison and determination of when a requirement is fulfilled.

4.4.4 MoSCoW

MoSCoW is a technique for prioritizing requirements based on 4 criterias, *Must Have* (Mo), *Should Have* (S), *Could Have* (Co), and *Won't Have* (W) [57].

Must Have includes the requirements that must be included in a final product. Requirements that are desired to be included in the product and have a high priority should be marked as *Should Have*. *Could Have* includes requirements that are desirable or nice to have, those should be implemented if it doesn't require too much effort or cost. Lastly, the *Won't Have* covers requirements that are desirable but that will not be implemented in this design [57].

4.5 Methods for Develop and Deliver

A design emerges through iteration, evaluation, and redesign. At an early stage, the focus is more on the conceptual model, including what the product will do and how it will behave. Later in the process of iterations, the focus shifts more toward the details of the design such as its graphics. In the same manner, the prototypes of the design evolve from simple lo-fi prototypes toward more high-fi prototypes that resemble the final product [4, pp. 421–422]. In this section, the methods used to generate, present, and evaluate the design in this project are presented.

4.5.1 Hierarchical Task Analysis

A Task Analysis (TA) is a tool for describing and understanding how people perform particular tasks. It can be used for different purposes, from describing behaviors to helping decide how to divide tasks. There are several methods for TA which can be used to describe users' tasks at different levels of abstraction [58]. A TA method used in this project is a Hierarchical Task Analysis (HTA). HTA is a tool for describing and understanding how people perform particular tasks and it is used to analyze complex tasks. The complex tasks are decomposed into a hierarchy of operations and suboperations and aim to identify what tasks are likely to fail due to poor design or lack of expertise [59]. An HTA takes the form of a graphical representation of a task structure. A sequence of tasks, sub-tasks, and actions are represented by structure charts as a hierarchy, where the order follows from left to right. Notational conventions are included to show whether an action can be repeated (iteration), and what alternative actions there are (selection) [36].

4.5.2 User Journeys

Gibbson [60] defines a journey map as "a visualization of the process that a person goes through in order to accomplish a goal". A User Journey is a specific application of journey maps that are useful to track the main moments of user interactions. It visualizes the interaction process, by highlighting the involved actors, their tasks, and the exchange of information among them. In the User Journey, each actor is represented in a column and associated with the others by a line. For each actor, their tasks are represented in chronological sequence along their line. The points of interaction between actors are highlighted and connects the actors involved as well as the action performed. Interaction points include both moments of communication as well when it is a need for an interface. The User Journey highlights who the user (considered for the analysis) is, how many other actors are involved, what type and frequency of interaction take place, and the complexity of those interactions [13].

4.5.3 Brainstorming

Brainstorming is a method for generating ideas, increasing creative efficacy, or finding solutions to problems [61, p. 2]. During a brainstorm, the participants should be encouraged to come up with a large number of suggestions without limiting them with restrictions. It is the imagination and creativity that sets the boundaries [62, p. 388]. The ideation should not be limited by criticism or any attempts to limit the type or number of ideas, the goal of the brainstorming is to have as many ideas as possible [61, p. 2]. When the ideation session is wrapped up, the suggestions from the brainstorming can then be collated, combined, expanded, refined, and prioritized as appropriate [62, p. 388]. With the aim of winnowing the collection of ideas into the most applicable to the problem [61, p. 3].

A specific type of brainstorming is the Crazy eight. Which is a method for generating a number or ideas in a short period of time. Each participant in the ideation session receives a paper and folds it into eight different sections, which is to be filled in with eight ideas in eight minutes. The focus of this method is to develop rough sketches on a variety of ideas. It is about quantity of ideas, and not quality [63]. However, the more open brainstorm method was does not limit the participants to eight ideas and allows for developing ideas further than what is possible if only spending one minute per idea.

4.5.4 Scenario-Based Design

Scenario-based design uses a concrete description of a future system at an early point in the development process. Where narrative descriptions of envisioned usage guide the development of the system. Scenario-based design is effective for changing the focus from defining functional specifications towards describing how people will use a system to accomplish tasks and other activities [64, p. 153], and consequently this method was chosen over detailed visual descriptions of product.

4.5.5 Storyboard

According to Sharp et al. [4, p. 426] a storyboard is a prototyping method used to describe a course of events through a series of illustrations that often is used in conjunction with scenarios. In interaction design storyboards are commonly used to show how a user solves a task step by step by interacting with a design. A storyboard in conjunction with a scenario provides stakeholders with more details and helps them imagine what it would be like to interact with the design.

4.5.6 Dot voting

Dot voting is an evaluation method used to individually vote on the importance of design ideas, features, or anything that requires prioritization in a collaborative session. Each person is given a number of dots used to quietly vote on the alternatives. For a weighted vote, the dots of each participant can have a number assigned to them to rank their votes [65].

4.5.7 Focus Group

In a focus group session, specific topics as discussed by a group of people, generally between four to twelve persons. A moderator ensures that the discussion flows and that the desired topics are covered. In addition, the moderator must also ensure all group members contribute to the discussion and that no participant dominates the conversation [66]. Focus groups have, compared to for example interviews, the strength of supporting discussions between participants. Further, O'Raghallaigh, Sammon, and Murphy [66] describes how the analysis and reporting of content and discussions from a focus group should include the meanings and implications for the research questions. Themes and descriptions of the participants' reactions to design features should be identified.

4.5.8 Pugh Matrix

In the final evaluation a criteria-based evaluation [61]. More specific, the method used was a Pugh Matrix which is a method for comparing design concepts and decision making. The Matrix consists of columns listing the different concepts, and rows with criteria for evaluation. In the cells in the matrix, each concept is ranked with a number for each criterion. Resulting in an overall score on how the concept performs in relation to the criteria. A Pugh matrix can have weighted criteria for a more nuanced evaluation. The outcome of the method is highly dependent on the quality of the input and evaluation criteria. A strength of the Pugh Matrix is that it shows the strengths and weaknesses of the concepts [67].

5

Process

This chapter describes how the project was executed, as well as how the methods were applied. This project follows the interaction design process, more in detail, the Design Council's [53] framework Double Diamond has been used to structure the work. This framework consists of the following four fundamental stages: Discover, Define, Develop, and Deliver.

During the Discover phase, data was gathered through interviews and observations to understand the users, their work situation, and the context of a food plant. This data was analyzed, and during the Define phase, the findings from the data were further used to define how to design the system of cleaning robots to fit the users' needs and the environment. During the Develop phase, concepts for how to design the interaction as well as evaluations took place. From this process, recommendations for how to design a system of cleaning robots were derived and presented in a scenario in the Deliver phase.

5.1 Discover

The first phase of this project included data gathering and analysis with the aim to gain an understanding of user needs and user behaviors. Learning about the context as well as the technical possibilities and limitations was also an important part of this phase. Interviews and discussions with the stakeholder companies of the RoboClean project were arranged to understand the system of robots and how it will work. Great emphasis was also put on user studies during this phase. As the system of robots investigated by the RoboClean Research Project is the first of its kind, no actual users exist yet. The approach taken was therefore to observe and interview people that represent the intended future key users instead. Observations of cleaning in food plants, as well as interviews with food plant cleaners, were held. Interviews with people working with system configuration and relating fields were also carried out. The data gathering was wrapped up with a thematic analysis, where conclusions could be drawn from the data gathered.

5.1.1 Data Gathering from Stakeholders

The project was initiated by visiting some of the stakeholder companies involved in the RoboClean Research Project. The primary purpose of these visits was to understand the system of cleaning robots. What is a system of cleaning robots? How will a system of cleaning robots work? What role do human users play in this system? During the visits, each stakeholder company presented their part of the work within the RoboClean Research Project and provided insight from their respective fields of expertise.

ABB

During a visit to ABB, the history of the project, the current status, and future expectations, as well as possibilities for this project, was shared. The visit also included an introduction to their research on a future cleaning robot and a demonstration of the mobile platform that will be used in the RoboClean Research Project. The capabilities and constraints of a cleaning robot and mobile platform were also discussed.

RISE

When visiting RISE, theoretical knowledge of how cleaning is done in food plants today and the challenges within hygiene and cleaning in the food industry were shared. In addition to theoretical discussions, a demonstration of cleaning in the food industry was also arranged in a realistic setting, inside a room for food production with strict hygiene regulations. During this demonstration, we got to observe the cleaning procedure as well as try out cleaning a food trolley ourselves. Instructions on what technique to use for an effective cleaning was given. The observation highlighted the individual differences in washing techniques and strengthen the understanding of the need for a systematic and optimized washing technique.

In another meeting with RISE, the development and aim of WML (Washdown Markup Language) were discussed. They described how today's descriptions of cleaning procedures are not adapted for robot programming use cases, and therefore a systematic way of describing the cleaning process and defining cleaning parameters is needed. This is the purpose of WML. Microbiologists at RISE are responsible for compiling data and knowledge on how to efficiently clean in the food industry, in other words, the content of WML. RISE explained that WML will be a central space for saving knowledge on cleaning. Additionally, the WML will contain all the knowledge needed to support the creation of good cleaning instructions that can be presented to human cleaners, as well as all the information needed for path planning and programming of a cleaning robot.

FCC

During a first meeting with FCC, they showed their IPS (Industrial Path Solutions) software and shared insight on how path planning could be applied to calculate cleaning patterns for a cleaning robot. The structure of WML and how it could be connected to the software and the robot were also discussed. Further, the capabilities and limitations of the path planning software were also discussed.

5.1.2 Data Gathering from Food Plants

Understanding the food plant contexts is essential. The current food plant cleaners were identified as the future system operators, and to gain an understanding of this user group was therefore crucial. Thus, with the aim of gaining an understanding of the context and the cleaners, observations took place in three different food plants. The focus during the observations was to deepen the understanding of what the context looks like, the cleaning tasks, and the cleaners.

Except for the first visit to Örneborgs Delikatesser, the observations followed a plan which covered the areas of Time and Space, Objects, Social Actors and Interactions, and Routines. The observation plan can be found in detail in appendix A. There are different ways to carry out observations, and these are usually categorized depending on the level of participation from the observer. Baker [54, pp. 173–177] categorizes the different roles an observer can take during an observation as Nonparticipation, Complete Observer, Observer-as-Participant, Participant-as-Observer, and Complete Participation are a few of them. In this case, the role as a complete observer was taken as this was what best suited the situation and context. The task was therefore to listen and observe, but not participate in the cleaning. Notes were taken to collect data systematically. Thereto, pictures were taken when allowed by the food plant.

Observation at Örneborgs Delikatesser

The first visit to a food plant took place at Örneborgs Delikatesser, a producer of mayonnaise based products. Lagafors, one of the partners in the RoboClean project, also took part in this visit. The visit included a guided tour of the plant followed by an unstructured interview with the technical manager at the plant and the CEO of Lagafors. Since this was the first time visiting a food plant for both of the authors, emphasis was put on observing, asking questions, and learning with an open mind. Therefore, no predefined questions or framework was used while observing during this visit.

The technical manager in the food plant together with the CEO of Lagafors (the company providing the plant with equipment for cleaning) showed us around the plant describing both the production and procedure and equipment for cleaning. During the visit, the workflow and cleaning procedure at this specific food plant was demonstrated.

Örneborgs Delikatesser produces a lot of different products for many different companies, which requires a lot of flexibility in production. Consequently, they had a low level of automation in the food plant and a high level of flexibility and uncertainty. At Örneborgs Delikatesser, the factory workers also cleaned their stations themselves regularly during a working shift. In addition to this, one big, thorough cleaning of the entire factory hall is done each night. This cleaning is done by the food production workers scheduled for the late shift, and accordingly, there was no designated cleaning personnel in this factory. From the observation, the understanding of cleaning in the food industry, as well as food production, was strengthened.

Observation at Charkuterifabriken AB

The second observation took place at Charkuterifabriken AB, a producer of meat products, such as ham, salami, and bacon. The visit was arranged by Lagafors. One representative from Charkuterifabriken was present during the visit to guide around the facilities and demonstrate the cleaning procedure. This representative was the cleaning foreman, employed by an external cleaning firm but with 2 years of experience from working at Charkuterifabriken AB. The cleaner demonstrated how the cleaning is done in a room inside the factory hall.

Cleaning occurs overnight at Charkuterifabriken AB and is performed by a cleaning firm. This factory was also bigger in comparison to Örneborgs Delikatesser and no change of product produced in the different machines took place which made the environment less uncertain. In general, this visit confirmed a lot of previous findings. The overall cleaning process looked the same, but with some individual variations in how specific things are done.

Observation at Lagerbergs Kyckling

A visit to Lagerbergs kyckling was arranged by the cleaning firm responsible for the cleaning of the food plant. Lagerbergs Kyckling is a food plant working with chicken, from slaughter to packaging. The visit included a tour through the entire food plant during production, guided by the manager of the cleaning firm and their manager for cleaning at site. This was followed by semi-structured interviews with the two representatives, an observation of the cleaning procedure, and general discussions about cleaning and food plants with factory employees.

The food plant at Lagerbergs kyckling is divided into three areas: slaughter, cutting, and packaging. The production in the slaughter area starts early in the morning and finishes at 13.00. Once production stops, the first cleaning shift begins. In the cutting area, production continues until 18.00, and this area is therefore cleaned during the evening. Lastly, the production in the packaging is ongoing until 00.00, and this area it thus cleaned during the night. The employees working the last cleaning shift finish their work around 04.00-05.00.

The cleaning followed the same overall procedure. Yet, one important difference was that the machines we put into a "cleaning mode" and were in movement during the cleaning.

5.1.3 Interviews with Cleaners

Interviews are generally used for gathering qualitative data, according to Sharp et al. [4, p. 269], and so are also other methods observations and focus groups. Interviews was however chosen for the purpose of gaining a better understanding of the intended key users and their needs, based on the wish to communicate with people working in the food industry one on one to get to know them better without them being influenced by other colleagues in the surroundings. 11 cleaners were interviewed in total. 2 of these cleaners were interviewed on site in the Lagerbergs Kyckling factory, and the remaining 9 cleaners were interviewed remotely over the phone. The interviews followed a semi-structured format. The format was chosen for its combined strengths of a structured and unstructured interview. Being open to exploring the topic further, but yet ensuring the same areas were covered through all interviews [4].

The following themes were covered in the interviews: Questions about the cleaner, questions regarding cleaning, questions about the use of technical solutions/aids, and thoughts about working with a robot. The questions can be found in detail in Appendix B. The duration of the interviews varied between 20-45 minutes, with a median duration of about 30 minutes. During the interviews, one interviewer asked all the questions from the interview script as well as probing, while the other interviewer took notes.

In Table 5.1 a description of the different participants can be found, including a short summary of their, age, gender as well as what activities in this project that they have participated in. The Focus Group was conducted at a later stage and will be described in the following chapters.

All of the interviewees worked at the same industrial cleaning firm. The interviewees had experiences with different kinds of food plants. Industries mentioned were the meat industry, chicken, charcuteries, bakery, confectionery, and mayonnaise based products. Different levels of experience were also represented among the interviewees, where some had worked in cleaning in the food industry for about 17 years and

ID	Age	Gender	Years working with cleaning	Interview on Site	Phone Interview	Focus Group
C1	30-39	Male	15-17	X		X
C2	30-39	Male	12-14	X		X
C3	18-29	Male	0-2		X	
C4	30-39	Female	3-5		X	
C5	30-39	Male	12-14		X	
C6	40-49	Male	6-8		X	
C7	40-49	Female	0-2		X	
C8	18-29	Male	3-5		X	X
C9	18-29	Male	0-2		X	
C10	50-65	Male	3-5		X	
C11	18-29	Male	0-2		X	X
C12	30-39	Male	0-2			X
C13	30-39	Male	0-2			X

Table 5.1: The cleaners who have been participating in this study.

others for less than one year. While the majority of the interviewees were currently working with the daily cleaning, a few participants had other roles like cleaning firm manager, site manager, foreman, and hygiene controller. Nevertheless, all participants had experience from cleaning themselves.

As described previously, the interviews followed a semi-structured format, and a predefined set of questions were supposed to be used for each interview. However, different challenges that emerged during some of the interviews required some adaption of the planned method. The semi-structured interview questions had been formulated in Swedish, but during a few of the interviews, it became apparent that there was a significant language barrier. In addition, translating into English was not an option either since the language barrier remained equally high. While interviewing these participants, this forces us to instead rephrase questions using a simpler language. An example of a simplification was that words like "fördelar och nackdelar" (pros and cons) had to be changed to "bra och dåligt" (good and bad). The format of the interviews is still considered to be semi-structured as the topic of the questions remained unchanged, but it cannot be excluded that these modifications possibly had an impact on some of the interviews.

5.1.4 Interviews about System Integration & Configuration

In comparison to the system operator, the intended users for the system configuration role were more challenging to define. Nonetheless, valuable insight about the future system configuration role could be provided by people working in fields related to robot system integration, configuration, and programming. Therefore, expert interviews were held with both system integrators and people with knowledge about robots and robot configuration to gain insights into the current system configuration profession and the professionals working within this branch. In Table 5.2 a description of the participants in the interviews can be found. Due to then uneven gender distribution in this industry, no women were found that could participate in the interviews. Alike the interviews with cleaners, the interviews followed a semi-structured format to ensure that the main topics were covered, but still open up for further probing and exploration.

ID	Age	Gender	Profession/Title
S1	30-39	Male	System Integrator
S2	40-49	Male	Robot Instructor
S3	50-65	Male	Automation Expert
S4	30-39	Male	Development Engineer at FCC
S5	30-39	Male	Licentiate Student at FCC

Table 5.2: The people interviewed about system integration and configuration.

Furthermore, the role of the system configurator was initially referred to as the system integrator. The decision to change the name of the key role to system configurator was taken first in the Deliver phase, during evaluation. System integration is a term traditionally used to describe projects where robot cells with stationary industrial robots and serving machines are built up. That is, a production environment is built up and adapted for the robot. In contrast, no significant adaption of the environment is required for the system of cleaning robots in the RoboClean Research Project. Instead, it is the system of robots that must be configured to be adapted for the existing production environment. The term system configuration was therefore found to be more suitable. However, as a result of this changing of name at a late stage, the term system integrator will sometimes be used interchangeably with system configurator during the process chapter.

Interview with System Integrator

An interview was held with a manager at a company working with system integration, offering services within machinery, equipment, and system integration. The food industry is a primary market to them, where they integrate systems for industrial processing of meat, fish, bakery, and other foods. They are a client to ABB that frequently integrates systems involving robots.

The interview covered the different steps of integration, what is needed and important during implementation, and the knowledge needed to integrate a system, following the semi structured interview that can be found in detail in Appendix C. Additionally, the interview also discussed the different employees at the company, what they do and what knowledge they have.

Interview with Robot Instructor

One person interviewed to further deepen the understanding of the role as a system integrator was a robot instructor at ABB. He educates the customers of ABB in softwares, programming, and safety, helping them to integrate their ABB robot. Thereby he has good knowledge of the procedure of system integration today and what knowledge is needed for successful integration.

The interview followed the semi structured plan which can be found in detail in Appendix C. In general, the interview covered the background and current role of the interviewee as well as how system integration takes place today and what knowledge is important for successful integration. In addition, the area of system integration of mobile and/or collaborative robots was also discussed.

Interview with Automation Expert

The same structure was followed for an interview with a Senior Automation Expert working with system integration. The interview deepened the understanding of the procedure of system integration in the industry. In addition to the other interviews, the importance for the integrator to understand the customer and their needs were highlighted.

Interview with FCC

FCC is developing the system that will be used to generate the robot path and cleaning pattern. To gain insights into how this system will work and what possibilities as well as constraints this results in for a system integrator, an interview in combination with a demonstration of the software took place.

The aim of the demonstration was to gain experience with the IPS (Industrial Path Solutions) software and how to interact with it. Further, this aimed for a deeper understanding of the demands the software puts on the system integrator as well as what possibilities it offers. During the demonstration, the role of Participant-as-Observer was taken where we were guided when interacting with the software, through the process of creating a path for the robot.

The interview that followed covered discussions about what steps are needed for the system integrator when working with the software and integrating the robot system. Thereby this also covered what tasks the software will be able to handle and what the system integrator needs to take care of. The interview aimed for an in-depth understanding of the future work with of interacting with the software and integrating the robot system.

5.1.5 Thematic Analysis & Affinity Diagram

Benyon [36] describes how data analysis is about finding and understanding themes that are more abstract than the raw data that has been gathered. The data collected in this project needed to be analyzed in a structured way to extract insights. A thematic analysis and affinity diagram was therefore used as a tool for a structured analysis. Sharp et. al [4] describe thematic analysis as one out of three commonly used approaches to analyze qualitative data, where the other two approaches are data categorization and identification of critical incidents. Thematic analysis was chosen before these other two approaches thanks to the support the method provides with creating a structure for big collections of data, and also since thematic analysis could successfully handle the diversity in the data we had collected. The thematic analysis was conducted to sort and analyze the data gathered from interviews with stakeholder companies, food industry observations, interviews with cleaners, and interviews with system integrators. To carry out the thematic analysis a digital affinity diagram was created. For this, the online software FigJam was used.

Initially, all pieces of data were put on color coded post its and sorted into overarching clusters. The color of the post its shows the source of the data. Grey marks all data from interviews with cleaners, yellow is data gathered from the observation at Lagerbergs Kyckling, purple is from the observation at Charkuterifabriken AB, green is from interviewing FCC, blue is from interviewing RISE, and brown is from interviews with system integrators. The post its was added to the FigJam wall gradually as the data was collected. Once all data had been collected and added to post its, a first round of sorting and clustering data took place. The clustering of post it notes was done in silence.

As this first round of clustering was done, a number of big clusters with post it notes had emerged. Next, these clusters were reviewed and rearranged into smaller clusters of post it notes. These new clusters were thereafter reviewed once again and further sorted until every cluster had a clear theme and also a placement in an overarching category. Once the sorting was finalized, each cluster was labeled with a theme formulated to describe how the notes in the category are related.

5.1.6 Themes & Insights drawn from Thematic Analysis

From this analysis, insights could be drawn. Additionally, the analysis also laid the foundation for the work in the Define phase. Once the over-arching categories and themes from the thematic analysis were set, these were revisited to further reflect on the content of each theme. For each theme, the content was summarized and described in terms of the insights gained from the themes. A review of the themes with a description on the corresponding insight can be found below, in Table 5.3, Table 5.4, and Table 5.5.

Insights about Cleaning

The table below presents the themes related to the work task of cleaning in food plants and a brief description of the insights drawn from each theme. After the table follows a more thorough description of each theme.

	Theme	Insights
T 1	**Cleaning environment**	Adapt for a wet, cold, smelly and noisy environment with a distinct division of rooms and limited free space.
		The uncertainty in the environment regarding the position of objects, level of dirtiness, and humans working in close proximity must be taken into consideration.
T 2	**Management of time, tasks and responsibilities**	Time is a crucial resource, but the time available can vary.
		There is a clear division of tasks between cleaners with personal responsibilities and management of work.
T 3	**Interactions between cleaners**	While working, little or no interaction takes place between the cleaners.
T 4	**Experience & Skills**	Despite standardized cleaning methods, the way people clean is individual.
		Knowledge and insight into the cleaning process is crucial for efficiency, the resulting cleanliness, and also to make sure machines and equipment don't break.
T 5	**Cleaning procedure**	Cleaning is done in more or less the same way in most food plants.
		Coarse rinsing takes up the biggest part of the total cleaning time.
		Continuous validation of cleanliness is needed between the different steps in the cleaning procedure, as well as when cleaning is done.
		Greater emphasis will be put on systematic cleaning preparations when a robot is introduced in this context.
		Cleaning requires reaching from different angles, high up, and low down. Sometimes doors on machines must be opened to reach everywhere.

Table 5.3: Insights about Cleaning

T1 Cleaning Environment

The cleaning environment inside a food plant is challenging from an interaction design perspective. Everything gets wet and the humidity is distinct. In many factories, the temperature is low. Food scraps are spread around, and depending on the kind of food processed the smell can be rather unpleasant. Machines are often running loudly and spraying water or chemicals also contributes to the high loudness level. Machines, production bands, and other equipment take up most of the space, limiting the accessibility when moving around in the facilities.

One insight based on this is how crucial it will be to adapt the interaction for this challenging environment. The dynamic environment also introduces a level of uncertainty to consider when designing the interaction. The position of objects like tables, trolleys, and machine parts can change from day to day and the distribution of dirt is never exactly the same. Furthermore, the idea of humans collaborating with the robot as well as working in parallel in close proximity to the robot also introduces uncertainties in the physical environment, as the settings might change from time to time.

T2 Management of time, tasks and responsibilities when cleaning

Everything needs to be clean when production starts again after cleaning, and there is no room for compromise regarding cleanliness or the time when it needs to be completed. Thus, time is a crucial resource.

When cleaning in food plants today, there is a clear division of work between the cleaners. Each cleaner has its own section in the food plant where they clean. Thus, a specific area is assigned to one specific cleaner, and unless there is a need for help to get the cleaning done in time no other cleaners are involved in the work in that area. It is the responsibility of the assigned cleaner. As long as the job is done in time, the cleaners manage their own tasks and work at their own pace. However, if working in the same room, they have to synchronize their work to ensure they are in the same step of the cleaning procedure.

T3 Interaction between cleaners

While working, little or no interaction takes place between the cleaners. Partly since they all work in different areas, often separated by walls, but also due to the noisy environment and hearing protection. However, if a cleaner works in the same room as other cleaners, there is a need to synchronize the different steps of the cleaning procedure, so that everyone starts to apply foam, rinse off foam and apply disinfectant at the same time. Some communication around this thus takes place.

If interaction takes place apart from this, it is usually when taking a break or when in need of help to get done in time.

T4 Cleaning experience and skills

As the cleaners are humans with different levels of experience, physics, and preferences, the way people clean is individual despite standardized cleaning methods. This individual variation should be kept in mind when designing for this group.

Further, the cleaners, as well as the managers, highlighted how knowledge and experience of the cleaning process are invaluable. It takes time to learn how to clean effectively, there is a significant difference in efficiency and resulting cleanliness between beginners and experienced cleaners. Also, with experience the risk of damaging machines and equipment reduces. The importance of cleaners knowing how to clean effectively is an interesting insight to bring forward into the design process as well.

T5 Cleaning procedure

In most parts of the food industry, the cleaning procedure and the steps involved overall look the same. However, the standard of the factory building with regard to sewers and ventilation affects the process. Further, the standard of its cleaning equipment also has an impact as the water pressure and kind of chemicals used affects how cleaning is done. There are naturally some variations in how to clean depending on what product is produced in the plant and what kind of machines are used for this. However, common for all food plants is that coarse rinsing takes up the majority of the time. An aid that can speed up this step of the cleaning procedure would thus have a significant effect on the overall time required to clean.

Due to inevitable uncertainties regarding the distribution of the dirt, a continuous evaluation is necessary to make sure all dirt is removed. When humans clean, they get instant visual feedback on whether there is any dirt left and where it is located, and the way they clean is adapted according to this feedback. Further, this visual feedback is crucial when cleaners determine if a step in the cleaning procedure is complete. An insight drawn based on this is that some kind of continuous evaluation throughout the cleaning process will remain important to assure cleanliness when introducing a robot.

When cleaning, the first step is to prepare the room. Sensitive areas are covered with plastic, certain parts of machines are removed, protective shields are opened, and positions of machine parts are adjusted. However, a human cleaner can always adjust and correct things in the room while working later on. This is not the case for a robot. Thus, when introducing a robot to this context even greater emphasis will be put on systematic cleaning preparations.

To clean efficiently and make sure all dirt is removed, it is also necessary to spray from different angles and heights. Further, machine doors sometimes need to be opened or positions adjusted on machines to reach everywhere. These are examples of cases observed where the robot might not manage on its own. Therefore, Human-Robot Collaboration when completing such tasks should be covered when designing the interaction.

Insights about the Cleaners

The table below presents the themes derived from the gathered data that relates to the people working with cleaning in food plants, and a brief description of the insights drawn from each theme.

	Theme	Insights
T 6	**Demographics**	Cleaners are mainly men in different ages with diverse ethnicity.
		Most cleaners in this study had no academic background and there is no specific vocational education for this job.
		Many have worked with other hands-on jobs before starting with the cleaning of food plants.
T 7	**Working as a cleaner**	Recruiting people for cleaning jobs in the food industry is difficult.
		Common ways to start working as a cleaner is through a recommendation from someone you know, or through the job center.
		Many cleaners at this cleaning firm are happy with their jobs, mentioning reasons like good managers, flexible scheduling, working independently, simple work tasks, and salary.
		There are a few things that cleaners find negative about the job, mentioning the unpleasant work environment, physical load, and working at night.
		If it was possible, cleaners would like to get help with tasks that are time consuming, heavy, challenging, and/or boring.
T 8	**Cleaners attitudes towards robots**	Cleaners are positive about new solutions to make their work easier.
		Many cleaners feel skeptical about a robot.
		Cleaners have little or no experience with robots.
		There is a fear of robots taking over their jobs.
T 9	**Interaction cleaner-robot**	There is a need for cleaners to interact with a robot remotely as well as in close proximity to it.
		A cleaning robot system could enable knowledge sharing from cleaning experts to cleaners working on the floor.

Table 5.4: Insights about the Cleaners

T6 Cleaner demographics

According to the findings from the data gathering, people working with the cleaning of food plants are almost exclusively men. The age of food plant cleaners, in general, varies between 25-60, but the elder workers in this span work in general with less physically demanding tasks. Regarding ethnicity, the group is diverse and many do not have Swedish as their native language. Former Yugoslavia, Romania, the Arab world, and Sweden are examples of the origins of cleaners encountered in this study. In general, cleaners have no academic background, but many have work experiences from other hands on jobs such as a construction industry worker, cleaners in hospitals and hotels, a truck driver, welder, car mechanic, and warehouse worker.

T7 Working as a cleaner

Managers at industrial cleaning firms are experiencing difficulties in recruiting people for cleaning jobs in the food industry. One cleaner described it as no one's dream job. Common paths into the occupation are through a recommendation from a relative or a friend. It is also common to get positioned at an industrial cleaning firm via the Swedish job center. Nevertheless, many cleaners participating in this study express that they like their jobs and refer to reasons like good managers, flexible scheduling, working independently, simple work tasks, and decent salary. Some however also point out that the cleaning firm they are working for seems to be a better employer with fewer issues of keeping personnel in comparison to other industrial cleaning firms.

Regardless, there are a few things many cleaners find negative about the job. The work environment is unpleasant with humidity, chemicals, low temperatures, and sometimes a bad smell. In addition, the physical load is significant, and some cleaners describe how it is wearing and tearing on their bodies. Primarily working at night is also an aspect of the job that many cleaners dislike. When asking cleaners what parts of the job they would like to get help with, different tasks that in some way are time consuming, physically heavy, challenging, or boring are brought up. If a robot could help with this to some extent, there is accordingly potential to meet some of the wishes of the cleaners.

T8 Cleaners attitudes towards robots

Cleaners have little or no experience with robots. When presenting the idea of a cleaning robot as an assistant in the future, most cleaners express skepticism. They express concerns about whether it will work at all, and if so whether it will actually make the work easier. In addition, some cleaners also raise concerns regarding robots taking over their jobs. On the other hand, almost all cleaners are positive about introducing new solutions that can make their work easier and more efficient. These attitudes will be important to keep in mind when working with the design of interaction and whenever involving this user group in the design process.

T9 Interaction cleaner-robot

The cleaners are, more or less, in constant movement when cleaning in a food plant. This will also be the case in a future when working together with a robot. The distance between the cleaner and robot will thus be varying, and the interaction should therefore allow for interaction in close proximity to the robot as well as remotely.

How well the cleaner knows the cleaning procedure affects the result. As it is today, this is something you learn from colleagues and develop over time, but by introducing a cleaning robot system, new ways to share knowledge about how to clean become possible. Information could possibly be conveyed from cleaning experts to cleaners through the system, a possibility that could be interesting to explore further when designing the interaction.

Insights about System Configuration

The table below presents the themes related to the work with robot system configuration and a brief description of the insights drawn from each theme. After the table follows a more thorough description of each theme.

	Theme	Insights
T 10	**Demographics**	People working in roles related to system configuration today are mainly men in different ages coming from diverse academic backgrounds, most of them related to tech and engineering.
		Many system configurators have a big interest in tech.
T 11	**Knowledge needed**	For system configuration of a cleaning robot system, competence within robotics and programming as well as an understanding of the food industry context, the cleaners, and the cleaning procedure in that context is needed.
		System configurators must be problem solvers and the work requires some knowledge from multiple related fields, such as automation, mechanics, electronics, 3D modeling, and safety.
		No role similar to the system configurator needed for the RoboClean system (with skills in mobile+collaborative robotics and cleaning) exists today.
T 12	**System configuration procedure**	When integrating and configuring a system, emphasis should be put on understanding the context, requirements, and needs of the client/the people working in the food plant.
		Work with system configuration takes place remotely (configuration, simulations) as well as on site in the food plant (testing, evaluation).

Table 5.5: Insights about System Integration

T10 System Configurator Demographics

Alike the cleaners, the people working in roles related to system configuration today are primarily men. They are of different ages, and they often have an academic background in engineering or similar tech-related educations. Many system configurators have a general interest in technology on a personal level as well, and several participants in the study brought up that they are eager to try out new technical solutions. Based on this attitude, it appears like there are great opportunities to introduce a new software as a tool for the system integrator. Nevertheless, it will important that this software is flexible enough to cover different levels of expertise, offering opportunities for the system integrator to perform both complex and simple tasks in an effective way.

T11 Knowledge needed for system configurators

Working as a system configurator requires knowledge in a lot of different fields, like mechanics, electronics, robotics, programming, and safety. They do not necessarily have to be experts in every field, but it is good to have a basic understanding of many different areas. Being interested in understanding how things work and tie together, as well as being a problem solver, are also important characteristics of a system configurator.

The future work of configuring a system of collaborative and mobile cleaning robots is predicted to require knowledge in robotics, and how the collaborative and mobile robot can be integrated in a safe way. Additionally, understanding of the food plant context, the cleaning procedure, as well as the cleaners will be important to ensure the configuration leads to an effective collaboration between the cleaner and the robot.

T12 System configuration procedure

The role as a system configurator of the cleaning robot includes dividing the tasks between the cleaner and the robot, therefore the understanding of the cleaning procedure for the specific food plant as well as the capabilities and constraints of the two parts are crucial for a successful integration. This understanding will lay an important ground when creating the workflow and paths for the robot.

The future work as a system configurator will include working in a software to create the paths for the robot, simulate the workflows and make adjustments until a favorable cleaning program is created. Subsequently, the cleaning program will have to be tested and evaluated in the real environment to ensure the solution is sufficient in the real world as well.

5.2 Define

During the Define phase the problem is specified based on the findings from the Discover phase. To define the problem, an image with a system overview was put together, personas were created, the procedure of cleaning today and the future configuration was described, and requirements for the system were specified.

5.2.1 System Map Overview

During the Discover phase, an understanding of what different parts the cleaning robot system contains and how these tie together was gained. To summarize and communicate this understanding, a system map illustrating the different parts of the RoboClean system was created. The system map was continuously elaborated on during the Define phase, and the map was also evaluated together with the project stakeholder companies ABB, RISE, and FCC. This resulted in the illustration in Figure 5.1.

The system map gave a valuable overview of the system, and also provided a good basis for discussions with stakeholder companies as well as participants in our study who were not familiar with the system. Discussing around an image helped to shape a common view of what the system should look like in the future.

Thanks to this deepened understanding of the internal relations of the system, the roles of and relations between the user groups also became more clear. Based on this, the target user groups could be further identified. The system configurator is the one who will configure the system of robots for a specific food plant, thus primarily interacting with the RoboClean Configuration Software, while the system operator is the cleaner working together with the robot in the food plant.

In addition, the user roles that will not be considered in this master's thesis could also be defined further. In this study, the cleaning expert working with the WML database and creating WML classes is not included. Nor will the producer of cleaning equipment who creates WML objects be considered, and the supervisor in the food plant monitoring the cleaning results without actually cleaning themselves is not involved either.

To not include these user roles in the scope of this master thesis was a decision based on primarily two reasons. Firstly, due to the need for delimitation. Focusing on additional user roles would have made the scope too big for the extent of a master's thesis. Secondly, the user roles that were chosen were found to be the most interesting roles from a User Experience point of view. The system configurator interacts during the initial setup of a system and is crucial in making the system work on site. Further, the result of the system configurator's work will have an impact on

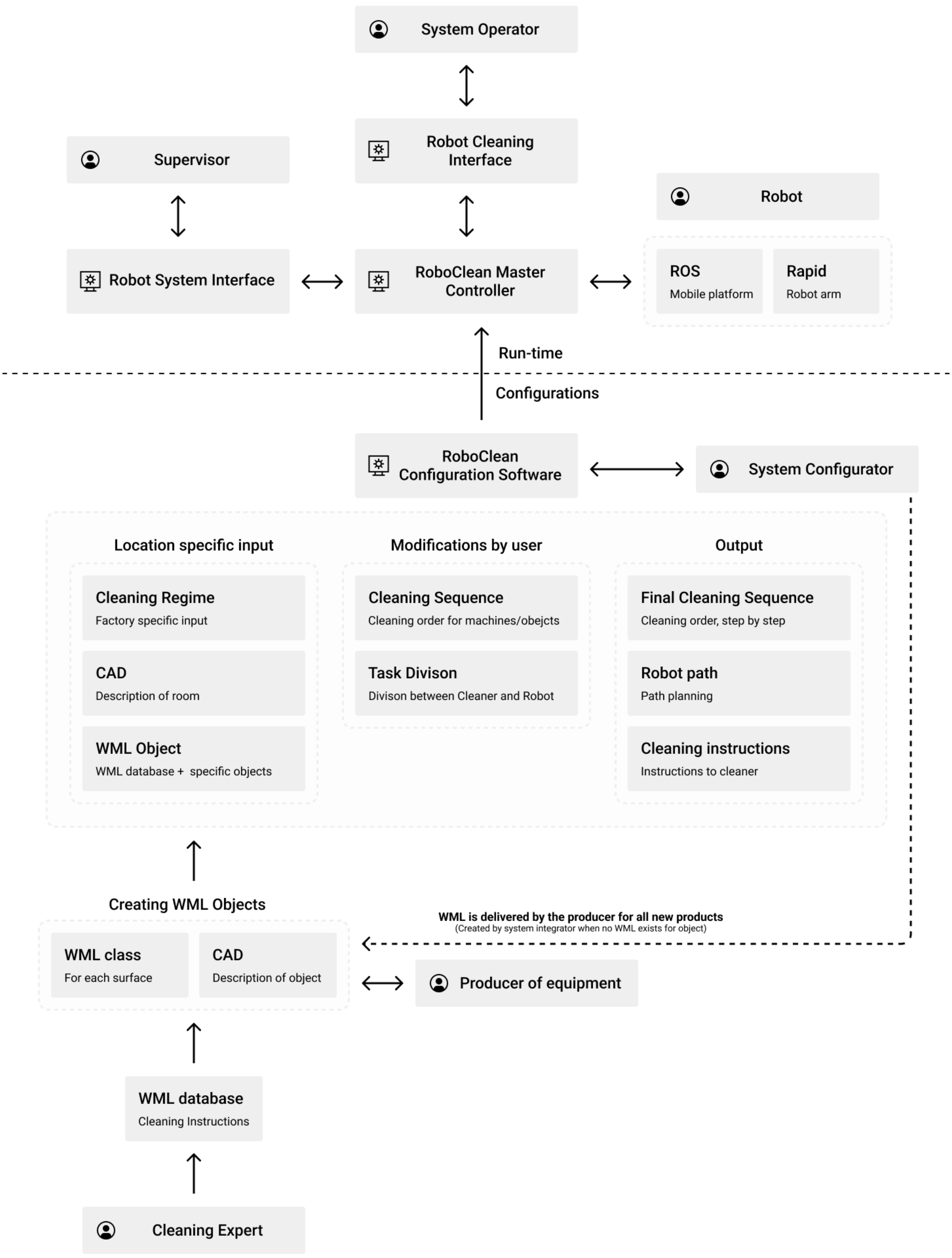


Figure 5.1: System Map

the User Experience of other users, the system operators. The system operator in turn interacts directly with the robot during operation in the daily work at the food plant. These roles were thus identified as primary, whilst User Experience aspects for a cleaning expert defining cleaning parameters for WML, a manufacturer producing cleaning equipment, or a system operator reviewing cleaning statistics from the food plant were found to be of less interest in a study focused on interaction with the system of cleaning robots.

5.2.2 The System Configuration and Operation Procedures

A deepened understanding of how cleaning currently is done in food plants was gained during the Discover phase. In similar, the Discover phase also gave an insight into what a future system configuration process could look like and what steps are necessarily based on what is known today. To summarize these findings in a clear and concise way, two lists describing the two procedures were put together and are presented below.

The Steps of System Configuration

1. Create a 3D model of the food plant
    - 3D model of food plant and all objects inside
    - WML objects for all objects inside
    - Factory specific cleaning parameters

2. Generate robot paths, object by object
    - Set parameters for path generation
    - Generate path describing how the robot will clean this object
    - Simulate and analyze path

3. Create a cleaning sequence
    - Define the cleaning sequence, in other words in what order the objects are cleaned

4. Generate a complete cleaning program
    - Generate robot paths describing how the robot will move between the objects according to the cleaning sequence
    - Simulate and analyze the cleaning of the entire room

5. Define HRI instructions for system operator
    - Define what information and instructions the system operator will need to complete the cleaning program

The Steps of Cleaning Today

1. Preparing the room
   - Remove objects that shall not be in the area during cleaning
   - Cover parts sensitive to water
   - Prepare the machines for cleaning by detaching the parts needed, place the parts in assigned places for cleaning

2. Coarse cleaning
   - Remove the food scraps that are particularly big
   - Rinse of all surfaces with water from top to bottom. The coarse rinsing is complete when no visible food scarps can be found

3. Apply foam
   - Apply foam from bottom to top on all areas
   - Leave the foam to react for about 15-30 minutes

4. Rinse of foam
   - Rinse of all foam from top to bottom

5. Inspect
   - Make an ocular inspection to ensure everything is clean

6. Apply disinfectant
   - Apply disinfectant from bottom to top on all areas
   - Leave the disinfectant to react for about 10-15 minutes

7. Rinse of disinfectant
   - Rinse of the disinfectant from top to bottom

8. Restore equipment
   - Mount back the parts detached from the machines in the beginning of cleaning and put back objects that has been moved
   - Uncover parts that have been covered during cleaning
   - Put back the hose

5.2.3 Personas

To further embody the findings about the two target user groups and their personal characteristics, personas were created. The purpose of creating these personas was to use them as a tool to keep the users in mind during the continuation of the design process, and to ensure the design is a good solution for the actual users. Arguably, personas are a good method for this purpose.

There are different templates and approaches to creating a persona, but for this project, the personas were based on an example provided by ABB. The personas personal background, demographics, knowledge, personality traits, goals, and frustrations were included together with quotes and a description of a typical day. Striving to paint a portrait as informative as possible, it was also decided to involve a bigger amount of text in the background and description of a typical day than ABB:s persona suggests.

As Sharp et al. [4] describe how the characteristics of personas should be anchored in attributes and attitudes from real users identified from data gathering, the personas were based on findings from the Discover phase. The Cleaner personas in this project are therefore based on findings from factory visits and interviews with cleaners.

Within the user group of cleaners, the findings from the user studies indicate that there were different, sometimes contradictory characteristics of typical users. In order to cover this variety, three different personas were created for the cleaner user group. The purpose of making three personas was to display these different characteristics and to give a better overall representation of the user group. Therefore, the cleaner personas include different work roles, different levels of experience, and a variety of technical knowledge and interest in adopting new technology. Similarly, a persona describing the future system configurator was created. This persona is based on interviews with professionals working in fields relating to this role, combining the skills needed and the personality traits of people with similar roles today. The skills needed are based on both the requirements the software and technology put on the system configurator as well as the needs for configuring a system in this environment. The data relating to this persona was less varied and a need for more than one persona was not found.

While the cleaner personas represent the cleaners of today, the persona for the system configurator represents a combination of the personality traits of system configurators today and the knowledge needed for working as a system configurator for this system of cleaning robots. Both types serve as a representation of the end users for this system of collaborative robots.

Salam

Salam has been employed by the cleaning firm for two years. He likes to do something where you can see the results of your work clearly, and he also appreciates the freedom of managing your own time while working. With a background working at a car service station before coming to Sweden, Salam has some technical skills. Nevertheless, he is skeptical about introducing robots to the cleaning business. What if robots take over his job...

Demographics

Age:	26
Native language:	Arabic
Location:	Blekinge, Sweden
Job:	Cleaner
Experience:	2 years in this industry
Education:	Vocational school

Knowledge

Cleaning procedure:

Robotics:

Technology:

Personality

Easy-going Impatient

Efficient Helpful

Goals

- Find new ways to execute the cleaning more efficiently to get work done as fast as possible.
- Take responsibility for his own area and work independently.

Frustrations

- Gets irritated when work is not done on time.
- Hates the feeling of not understanding something.
- He speaks a little Swedish, but the language barrier still annoys him. He dislikes to admit when he doesn't understand something.

Quotes

"The best thing about this job is the flexibility and freedom. I work in my own pace."

"I had a hard time finding work, but then a friend recommended me for this job."

A typical day

Salam lives alone in a one-room apartment. He typically sleeps until 14.00, then meets up with some friends to watch football or hang out at the local pizzeria driven by his friend. His cleaning shift begins at 23.00, but he has to be there at least 15 minutes before to have time to change clothes.

Salam is responsible for cleaning one of the rooms in the plant. He has been cleaning this room for several months now, so completing the cleaning procedure goes on autopilot. Since he is working alone in this section, it is a safety requirement to bring a phone. Salam likes this because it also means that he can use his phone to listen to music while working. He would never want to work without listening to music.

Salam works systematically and fast. Rinse, foam, rinse, disinfectant. He constantly strives to refine his cleaning technique in search for the most efficient way to do his tasks. Sometimes he even skips taking breaks to get done faster. Salam knows the cleaning instructions and the regulations in the food plant very well, and he follows them almost always. However, some safety regulations might start to seem exaggregated with time. As a result of Salam's efficient way of working he is done at work half an hour earlier than most of his colleagues. Happy with his accomplishment, he returns home to sleep.

Figure 5.2: The Cleaner Salam

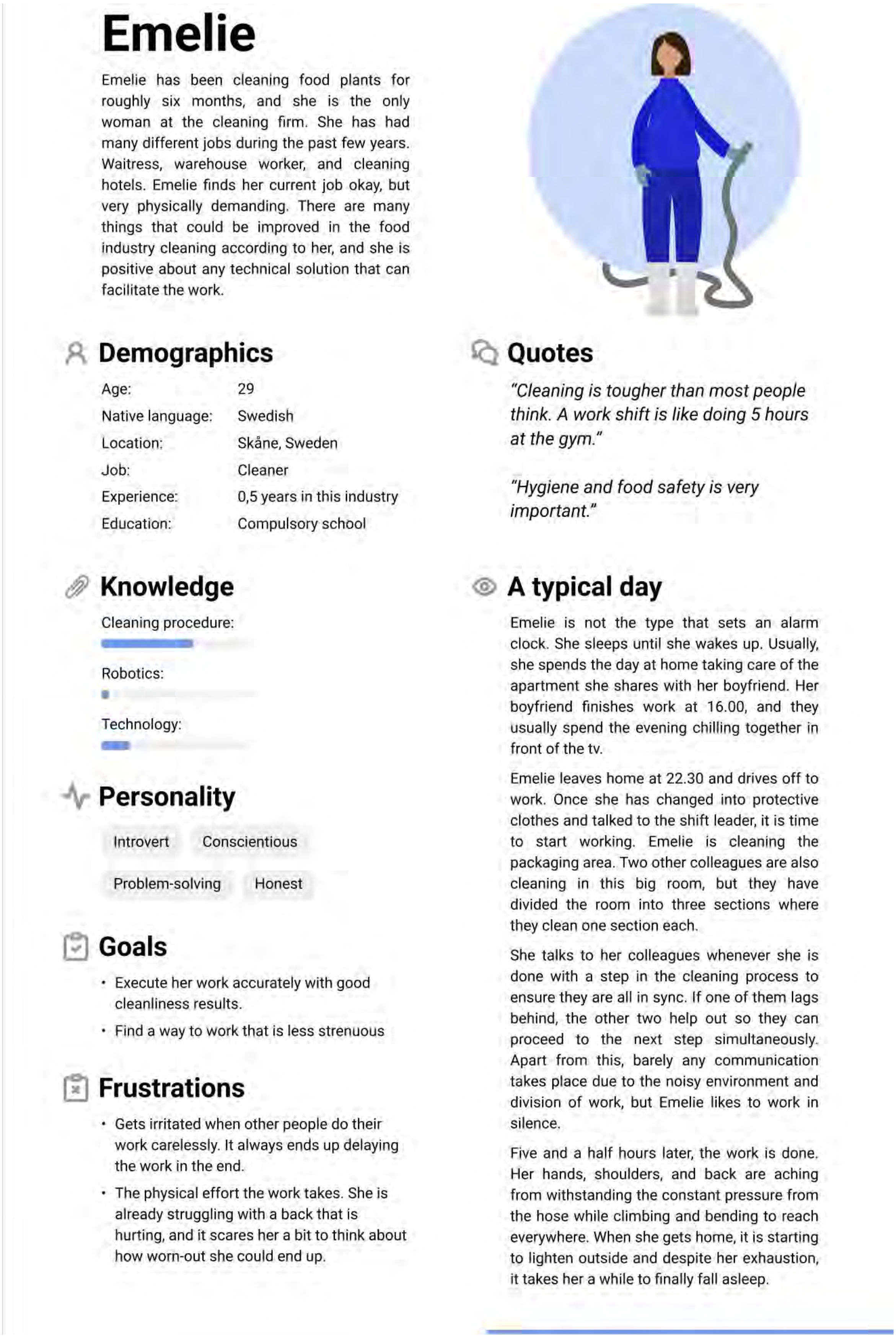


Figure 5.3: The Cleaner Emelie

Nikola

Nikola works as shift leader for a team of cleaners in a food plant. He has been working within the same cleaning firm for more than a decade, and his experience at work is invaluable to his managers. Nikola likes his job and thinks everything works well the way it is today. More or less, at least. He has no previous experience with robots and has little interest in new technical solutions for the cleaning industry.

Demographics

Age:	48
Native language:	Serbian
Location:	Halland, Sweden
Job:	Cleaning shift leader
Experience:	11 years in this industry
Education:	High school

Knowledge

Cleaning procedure:

Robotics:

Technology:

Personality

Hard working · Habitual · Reliable · Efficient

Goals

- To gain responsibility within the cleaning firm by being good at what he does.
- Supervise and support the cleaning team to streamline the cleaning process.
- Keep an overview of how the cleaning is progressing in all parts of the food plant.

Frustrations

- Dislikes change. Changes in the factory usually only cause him and his colleagues problems. Why change something that already works?
- Even if he is used to it by now, the late working hours can be frustrating.

Quotes

"It is a great job! It is not for everyone, but I think it is great."

"Having the work done by skilled cleaners will always be cheaper and more efficient. A robot would only complicate things."

A typical day

When Nikola wakes up around 12.00, the house is empty. His wife is at work and his daughter is at school. Once thet get home later on in the evening, the family has dinner together. Afterwards, Nikola drives his daughter to a football practice. Around 22.15, Nikola leaves home for work and parks the car outside the food plant at 22.45.

Just before the cleaning shift starts, Nikola gathers the group of 11 cleaners and briefs them about the work for tonight. Last night, one of his cleaners accidentally damaged one of the machines due to one carelessly attached protective plastic cover. He therefore gives an extra reminder about the importance of careful preparations to his team.

The cleaning shift begins at 23.00. As the cleaning shift leader, Nikola circulates between the different rooms of the factory to organize and supervise the work. Whenever someone lags behind, he helps them out. Keeping track of everything that happens inside of the large food plant can be quite stressful at times, and Nikola is constantly on the move. This night, Nikola also really strives to spend some extra time with the newest cleaner on the team to tutor and support him.

The time is slightly past 04.30 when the last section of the plant is cleaned and controlled. Nikola drives home and lies down in bed beside his sleeping wife.

Figure 5.4: The Cleaner Nikola

Sam

Sam is employed by a tech consultancy firm and has been working with system integration and configuration for nine years. He really likes the job since he gets to make use of a wide range of skills. No two days are the same and Sam is challenged to solve new problems every day. Tech is not only Sam's profession, it is one of his biggest interests. He strives to be an early adopter within tech and he is always eager to try out to new technical solutions and gadgets.

Demographics

Age:	44
Native language:	Swedish
Location:	Västerås, Sweden
Job:	System configurator
Experience:	9 years in this industry
Education:	Engineering degree

Quotes

"Systems of cleaning robots are the future of food plant cleaning"

"You can solve anything with technology – the bottleneck is lack of time and resources"

Knowledge

Cleaning procedure:

Robotics:

Technology:

A typical day

Sam's alarm rings at 06.30. He make sure to get the kids and himself ready for the day, and then Sam leaves for work on his bike. At work, the first thing Sam does is to head over to the kitchen and grab a coffee and say good morning to his colleagues. It is first once Sam has consumed a sufficient amount of caffeine that he is ready to get started with the workday.

Sam has just started working on configuring a system of cleaning robots in a meat cutting factory. The other day, he went for a visit there to see the environment, document it, and talk to cleaners about their work.

Now, Sam is working on building the virtual environment for the digital twin that will be used for configuring the system including every machine and objects within it. The model of the environment is needed to be able to configure the way the robots will clean the food plant. He has to be thorough and Sam spends the entire day working on this task.

At 17.00 sharp, Sam leaves the office. The evening is spent driving his youngest child to dance rehearsal, helping his eldest rehearse Enligh glossary, and going for a walk with the dog. After saying goodnight to his kids, Sam and his partner watch an episode of the crime series they are currently following before finally going to bed.

Personality

Analytic · Social · Thoughtful · Tech nerd

Goals

- Streamline cleaning processes.
- Configurate systems that work well and meet the requirements of the users.

Frustrations

- People who think they can program a robot just because it is so much easier these days, but have no proper education and completely lack knowledge in robot safety.
- Poorly built virtual food plant models. A tiny deviation in the model can have a major impact on the suceeding steps.

Figure 5.5: The System Configurator Sam

5.2.4 Scenario

A scenario was also written during this phase of the master's thesis. There was a need of summarizing the findings of how cleaning is done today in a comprehensible and descriptive way that could make others emphasize with the user group and understand their work situation. Therefore, this method was chosen. The narrative follows the main persona Salam during a work shift. It describes the context and some of the activities involved when cleaning in a food plant, and it also brings up some of the work related thoughts, feelings, and goals that cleaners' expressed during interviews.

Cleaning a food plant today

Salam is working as a cleaner in a food plant producing charcuterie products. To ensure food quality and safety, the requirements on hygiene and cleanliness are extremely high. The cleaners work is a prerequisite for enabling the rest of the production to take place and one could thus argue that they are the most important workers in the food plant, but Salam does not feel that way. To Salam there is no professional pride in being a cleaner, it is just a job he has to do to make a living. A rather heavy and overall unpleasant job to be honest. No one would ever say it out loud, but the cleaners are rather seen as the workers with the lowest status within the food plant.

Salam is employed by an industrial cleaning firm and has been cleaning in this particular food plant since the start of his employment two years ago. Salam first heard about this job opportunity from an acquaintance. At that point, he had been looking for a job for quite some time and was in urgent need of employment. Despite this, he was hesitant about the industrial cleaning industry at first, considering the tough work conditions. Working hours are during nighttime, the work can be quite stressful and the work tasks are heavy and unpleasant. Nevertheless, Salam's acquaintance convinced him to give it a try and he is happy about that decision now. Working as a food industry cleaner is no one's dream job, but it is a job, and the salary is decent. What matters to Salam at the moment is that he gets his monthly paycheck and the security of permanent employment.

The cleaners' shift begins when the production stops around 23.00. The cleaning team has 5 hours to clean the entire food plant, and time pressure in combination with a lot of different tasks makes the procedure quite stressful. No time for chilling in the coffee room.

Before entering the factory hall, Salam changes from his regular clothes into workwear. First, he puts on a white coat, trousers, and hat. These are the same kind of clothes that all workers in the food plant wear. To avoid wearing beard protection, the beard must not grow longer than 3 mm. Salam, therefore, tries to shave daily to avoid the disturbing plastic net that is worn over the chin. Thereafter, he puts on another layer of clothes that is specific for the cleaners. These pieces of clothing are made from a blue, water-resistant fabric that looks like it is PVC-coated. Finally, he also puts on a pair of rubber boots, rubber gloves, hearing protectors, and protective googles.

After the change of clothes, Salam heads towards the washing area that separates the food production from the rest of the factory. Here he washes his hands thoroughly and applies disinfectant to them. Once this step has been completed, he is ready to enter the food production area.

Salam is responsible for cleaning one of the rooms in the plant. He has been cleaning this room for several months now, so the different steps of the cleaning procedure goes on autopilot. Since he is working alone in this section, it is a safety requirement to bring a phone. Salam likes this because it also means that he can use his phone to listen to music while working. He would never want to work without listening to music.

Salam presses "play" on one of his favorite playlists and begins to prepare the room for cleaning. Some parts of the machines are sensitive to water, and these must be protected with a plastic cover while cleaning. Other parts should be removed from the machines and cleaned separately. On some machines, there are also doors and slots that need to be opened. Salam also collects all trolleys and places them in one part of the room.

Once the room is prepared, it is time to start with the coarse cleaning. In this food plant, the Lagafors cleaning system has been installed. Accordingly, Salam goes to fetch the hose from the Lagafors central mounted on a wall. He puts on the right nozzle and turns on the water. Pressured water begins to flow loudly and Salam starts to rinse off the walls, machines, and other objects inside the room. The goal of this initial step is to rinse with water until there is no visible dirt left. To reach every little corner of the machines Salam has to both bend down and climb machines.

Rinsing takes time. Salam works systematically when rinsing off the machines, from top to bottom, focusing on one machine and its surrounding walls at a time. The uneven and scattered distribution of the food scraps however forces Salam to sometimes rinse repeatedly in certain areas. Since the Lagafors pump station provides pressured water, one must also be careful about the rinsing angle, to ensure that no water or dirt comes splashing onto clean areas.

Salam remembers how he used to find this step surprisingly challenging at first, but after a few weeks of working in the food plant, he got hold of the rinsing technique. However, swiping the room with water back and forth is monotonous work, and the vibrations caused by the pressured water are physically tiring. When opening machine doors or cleaning loose objects, Salam is forced to work with both hands, holding the object in place while rinsing. The noise from the water hose is loud and constant, but the hearing protectors at least take away some of it.

While working, the room gets increasingly humid and the floor is soaked with water and food scarps. When the machines and walls look clean, it is time to take care of the floor flooded with water and food scarps. Salam grabs a floor scraper and starts to shuffle food scraps towards the sewers. The sewers get clogged with food every now and then, so he must pause the scraping to cleanse them regularly.

Finally, all surfaces look clean and Salam can move on to the next step in the cleaning procedure. Time to apply the chemical foam. He mounts the foaming nozzle onto the hose and holds it pointing downwards while turning on the supply of chemical foam and pressured air on the Lagafors station. The chemical foam starts spreading with a "poff" and Salam begins to distribute the foam evenly over all surfaces in the room straight away.

Salam must keep the nozzle in motion to avoid accumulating too much foam in one place. The formula of foam is designed to remain foamy even after it has been applied to better stick to surfaces, and for an inexperienced cleaner, it can quickly become too much foam. The foam should be applied starting from the bottom and up, but except from that, every cleaner has his or her own special technique for doing this. Salam thinks it works best to just move at a calm pace and work in a structured pattern. Sometimes, when cleaning trolleys, for example, he also turns off the pressured air to reduce the volume of the foam even though this is against the instructions. Once all surfaces have been covered in foam, Salam goes back with the hose to the Lagafors central and turns off the supply. The foam should now be left to react for about 10-15 minutes.

Once enough time has passed, Salam changes back to the nozzle for water and turns on the water supply again. When he starts rinsing off the foam with water, the resistant character of the foam becomes evident. Instead of resolving into the water and floating away down the drains, the foam just shuffles around on the floor. If it was not already clear, it is now obvious why the cleaners wear rubber boots. Salam keeps rinsing until no remains of foam can be seen on the machines and walls, again he needs to be thoroughly and sometimes return to already rinsed areas to ensure every little corner is clean. Ultimately, it is time to take care of the floor flooded with water and foam. Salam returns the hose and rolls it up on a spinning wheel next to the Lagafors station. Thereafter, he grabs a floor scraper and starts to shuffle foam towards the sewers. When the foam is accumulated around the sewers, he gets the hose again to rinse off the chemicals from the floor with water. What remains of the foam is left to resolve over time. Then, the same procedure as when applying the foam follows as Salam applies and rinses off a disinfectant to the machines. Tired and with aching back and shoulders, Salam finishes by restoring the room so it is ready for production tomorrow again. Finally, Salam declares the cleaning of this room done.

5.2.5 Requirements List

A list of requirements is a collection of requirements on a design identified and extracted from the data gathering [4]. Based on the thematic analysis in this project, requirements for the system of cleaning robots were identified. The requirements are divided depending on if they relate to the configurator or the operator of the system. The requirements relating to the configurator can be found in Figure 5.6, 5.7, and 5.8, and the ones relating to the operator in Figure 5.9 and 5.10. The requirements are prioritized according to the MoSCoW model. Thus if the requirements are something that the design "Must Have", "Should Have", "Could Have", or "Won't have".

The requirements in the following lists are marked with where the information that led to this requirement came from. Requirements marked as S are based on information provided by stakeholder companies, U are based on user studies, and L are based on findings from academic literature.

Nr			Requirement	S	U	L
1.	Configuration software **must** enable adding the required input			X	X	
	i.	**Must** be possible to add CAD files		X	X	
		a.	CAD file describing the environment of the food plant (including floor, walls, etc)	X	X	
		b.	CAD file for each object inside the room	X	X	
	ii.	**Should** be possible to add WML objects		X	X	
	iii.	**Must** be possible to add parameters of the food plant		X	X	
		a.	Water pressure	X	X	
		b.	Water temperature	X	X	
		c.	Type of chemicals	X	X	
		d.	Type of dirt	X	X	
		c.	Other	X	X	
2.	Configuration software **must** enable building a virtual 3D representation of the food plant			X	X	
	i.	**Must** be possible to place WML objects inside a 3D representation of the food plant layout		X	X	
3.	Configuration software **must** support the user with generating robot paths for cleaning an object			X	X	
	i.	**Should** provide path generation parameters		X	X	
		a.	Provide possibility to edit path generation parameter	X	X	
		b.	Provide possibility to accept path generation parameter	X	X	
	ii.	**Should** be possible to split large surfaces into smaller surfaces where needed		X	X	
	iii.	**Must** be able to generate a path based on path generation parameters		X	X	
		a.	Provide possibility to edit path	X	X	

Figure 5.6: Requirements Configuration part 1

Nr			Requirement	S	U	L
4.	Configuration software **must** support the user with putting together a cleaning program			X	X	
	i.	**Should** create a cleaning sequence		X	X	
	ii.	**Should** offer the possibility to edit a cleaning program		X	X	
		a.	Provide possibility to edit the cleaning sequence	X	X	
		b.	Provide possibility to edit the division of work	X	X	
5.	Configuration software **must** provide the possibility to simulate cleaning			X	X	
	i.	**Must** be possible to simulate cleaning of a single object		X	X	
	ii.	**Must** be possible to simulate a whole cleaning program		X	X	
6.	Configuration software **must** provide support for test running a cleaning program on site				X	
	i.	**Must** be possible to test the program safely		X	X	
		a.	Without risk of harming humans	X	X	
		b.	Without risk of damaging the food plant	X	X	
	ii.	**Must** be possible to analyze and refine a cleaning program when test running it on site		X	X	
7.	Configuration software s**hould** provide the possibility to create new WML objects			X	X	
	i.	**Should** be possible to connect WML classes from WML database to surfaces in CAD files		X	X	
	ii.	**Should** be possible to connect WML classes to walls, floors and other parts of the factory layout		X	X	
8.	Configuration software **should** suggest an optimal option as default whenever possible			X		
	i.	Optimal cleaning parameters based on the situation **should** be suggested		X		
		a.	Manual adjustments of cleaning parameters **should** be possible	X		
	ii.	Configuration software **should** generate paths with optimized cleaning angles		X		
		a.	The cleaning programs **should** take the spreading of water into account	X		
		b.	The cleaning programs **could** take the spreading of foam into account	X		
		c.	The cleaning programs **could** take the spreading of disinfectant into account	X		
		d.	The cleaning programs **should** take the spreading of food scarps into account	X		
9.	Configuration software **should** support the user with the analysis of a cleaning path for an object			X	X	
	i.	**Should** provide information about the reach of the robot		X	X	
	ii.	**Should p**rovide information about the coverage degree		X	X	
	iii.	**Should** provide information about cleanliness result		X	X	
	iv.	**Should** provide information about time		X	X	
	v.	**Could** provide information about use of resources		X	X	
10.	Configuration software **should** support the user with the analysis of a whole cleaning program			X	X	
	i.	**Should** provide information about division of work between human and robot		X	X	
	ii.	**Should** provide information about cleanliness result		X	X	
	iii.	**Should** provide information about time		X	X	
	iv.	**Could** provide information about use of resources		X	X	
11.	Configuration software **should** support an iterative process			X	X	
	i.	**Should** make it easy to simulate and evaluate often		X	X	
	ii.	**Could** present results in a way that is easily understandable also for someone who does not know the program to facilitate evaluation with other stakeholders (factory workers like cleaners, technicians, managers etc.)		X		
	iii.	**Could** allow for making updates quick and easy		X	X	

Figure 5.7: Requirements Configuration part 2

Nr			Requirement	S	U	L
12.			Handling of uncertainties in the environment **should** be planned for during configuration	X	X	
	i.		Instructions on how to handle trolleys and other loose objects **should** be established and communicated		X	
	ii.		Instructions on how to place objects at precisely specified location inside the room **should** be established and communicated	X		
		a.	There **could** be markings on the floor where an object should stand	X		
		b.	Objects **could** be attached to the floor so they are no longer movable	X		
		c.	Most loose objects **should** be removed by a human before starting the cleaning program	X		
	iii.		Instructions on what state machines should be put in **should** be established and communicated		X	
13.			Configuration software **should** support the user in creating an optimal division of work between cleaner and robot	X	X	X
	i.		**Should** help the user to define what/when the cleaner need to support the robot with cleaning		X	
	ii.		**Should** help the user to define what should be done between different steps of the robot cleaning program	X	X	
		a.	Define when confirmations from cleaner are required for the robot to proceed to the next step in the cleaning program	X	X	
	iii.		The division of work **should** promote the best possible work situation for human workers	X		
	iv.		The division of work between robot and cleaner **should** promote an optimised cleaning procedure in terms of efficiency		X	
	v.		The division of work between robot and cleaner **should** establish that the robot is supervised by the human and not vice versa		X	X
14.			Configuration software **should** generate a systematic and efficient cleaning sequence	X	X	X
	i.		Robot and cleaner **should** move from object to object systematically	X	X	
	ii.		The layout of the room and placement of objects inside the room **should** be taken into consideration	X	X	
15.			Configuration software **should** generate optimized cleaning programs in terms of efficiency	X		
	i.		Cleaning programs **should** minimize water usage	X		
	ii.		Cleaning programs **should** minimize chemical usage	X	X	
	iii.		Cleaning programs **should** minimize disinfectant usage	X		
	iv.		Cleaning programs **should** minimize cleaning time	X		
	v.		Cleaning programs **should** give instructions to rinse from top to bottom when rinsing with water		X	
	vi.		Cleaning programs **should** give instructions to apply from bottom to top when applying foam/disinfectant		X	
16.			Configuration software **should** support the user in creating HRI		X	
	i.		**Should** support the user in defining different cleaning programs in HRI		X	
	ii.		**Should** support the user in defining preparations needed in HRI		X	
	iii.		**Should** support the user in defining required confirmations in HRI		X	
17.			Configuration software **could** support the user in defining instructions for HRI	X	X	
	i.		**Could** help the user to make instructions for what preparations are needed		X	
	ii.		**Could** help to the user to define what instructions to send to the cleaner while cleaning	X	X	
	iii.		**Could** help to the user to define what instructions to send to the cleaner in-between different steps of the cleaning procedure	X	X	
18.			Configuration software **could** generate modular cleaning programs with flexible cleaning sequences		X	
	i.		The order in which the objects are cleaned **could** be changed by the cleaner		X	
	ii.		If the robot cannot start cleaning the object next in turn in the cleaning sequence due to insufficient preparations or other obstacles, it **won't** postpone the cleaning of this object and move on to the next object in the cleaning sequence		X	
19.			Configuration software **won't** be able to simulate and optimise work by human cleaners	X		
20.			Configuration software **won't** be able to create cleaning programs autonomously	X		
21.			Configuration software **won't** be able make updates to a cleaning program while running in real-time	X		

Figure 5.8: Requirements Configuration part 3

Nr			Requirement	S	U	L
22.	HRI **must** provide cleaner with control over the situation			X		X
	i.		The cleaner **must** be able to control the robots basic functions (i.e. start, stop, select cleaning program)	X		X
	ii.		The cleaner **should** experience that he/she is in control	X		X
	iii.		The robot **should** be experienced as an assistant to the cleaners, and not vice versa	X		
23.	HRI **must** be safe			X	X	X
	i.		The robot **must** not do anything that could harm humans severely	X	X	X
	ii.		HRI **must** not provide cleaner with options that could damage the robot, the environment or other humans	X	X	
	iii.		HRI **should** enable the cleaner to overlook the environment while interacting		X	
	iv.		Cleaner **must** be provided with emergency stop at any time		X	
24.	HRI **must** provide the cleaner with information about what the robot is doing				X	X
	i.		**Could** communicate what have been done	X	X	
	ii.		**Should** communicate what it is currently doing		X	X
	iii.		**Should** communicate what it is about to do		X	
	iv.		**Should** communicate what it will not do		X	
	v.		**Must** communicate if something is wrong		X	
25.	HRI **must** communicate when and how the robot needs support from the cleaner			X	X	
	i.		**Should** give instructions on preparations before it starts the cleaning procedure	X	X	
	ii.		**Should** give instructions when an object or machine needs adjustments		X	
	iii.		**Must** give instructions when the robot can not clean something	X	X	
		a.	When a surface/object is out of its range	X	X	
		b.	When a surface/object is to complex for the robot to clean	X	X	
		c.	When a surface/object is known to be especially difficult to clean	X	X	
26.	HRI **must** be adapted for the environment in a food plant				X	
	i.		HRI **must** be fully functional in a wet environment		X	
	ii.		HRI **must** be fully functional in a dirty environment		X	
	iii.		HRI **must** be fully functional in a noisy environment		X	
	iv.		HRI **must** be robust and withstand wear and tear		X	
	v.		HRI **must** meet the hygienic requirements of the food plant		X	
	vi.		HRI **should** work independently of how light/dark the room is	X	X	
27.	HRI **must** be possible while wearing protective clothes and equipment				X	
	i.		Gloves		X	
	ii.		Rubber boots		X	
	iii.		Glasses		X	
	iv.		Helmet		X	
	v.		Hearing protectors		X	
	vi.		Face mask		X	
28.	HRI **should** be possible from a distance				X	
29.	HRI **should** be able to give the cleaner notifications from robot				X	
	i.		HRI notifications **should** be independent of distance between robot and human		X	
	ii.		HRI notifications **should** not be too intrusive		X	
	iii.		HRI notifications **could** give additional information about the character of the information which the cleaner is notified about		X	

Figure 5.9: Requirements Operation part 1

Nr	Requirement	S	U	L
30.	HRI **should** allow for mistakes by cleaners		X	
	i. Feedback helping user understand the results of an action **should** be provided		X	
	ii. User actions **should** never be irreversible		X	
	a. **Must** always be possible to stop	X	X	
	b. **Should** always be possible to pause		X	
	c. **Could** always be possible to change a choice that has been made		X	
	d. **Could** always be possible to go back		X	
31.	HRI **should** be possible with elementary language proficiency	X	X	
	i. Instructions **should** be available in different languages	X	X	
	ii. Any text-based information **should** make use of simple and easily understood wording	X	X	
	iii. Text-based information **should** be complemented with wordless means of communication such as illustrations/icons/images	X	X	
32.	HRI **should** be designed for users with limited technical background		X	
33.	HRI **should** express robustness		X	
	i. Cleaners **should** not be held back or have to adapt their work to any greater extent due to fear of breaking the device/robot/other mean of interaction		X	
34.	HRI **should** give cleaner information about how to clean	X	X	
	i. **Should** suggest optimal cleaning parameters	X	X	
	ii. **Should** give instructions on a suggested order for executing cleaning tasks	X	X	
	iii. **Could** provide more detailed information about how to clean a certain object	X		
35.	Placement of HRI **should** be accessible		X	
	i. HRI **should** be easy to access when the cleaner wants to interact with it		X	
	ii. HRI **should** be accessible while interacting		X	
	iii. HRI **should** be possible to place in a good way while working		X	
36.	If HRI medium is carried/worn by the cleaner, the comfort of the cleaner **should** be considered		X	
	i. Weight of HRI medium **could** be considered		X	
37.	If HRI medium is portable, it **could** have a dedicated placement while not used		X	
38.	HRI **could** preferably be possible with using only one hand		X	
39.	The number of times a cleaner interacts with the robot **could** be kept down		X	
40.	Robot **could** ask for and wait for approval before moving on to the next cleaning phase		X	
41.	The design of the HRI **could** support mapping of the relationship between interaction HRI medium and robot		X	
42.	The cleaner **won't** be able to make changes from the "normal" cleaning procedure		X	
	i. Add more objects/machines/areas to the procedure		X	
	ii. Remove objects/machines/areas from the procedure		X	
43.	The robot **won't** have a feedback system where a cleaner can confirm or reject the cleaning result used to continuously improve the cleaning program	X		

Figure 5.10: Requirements Operation part 2

5.3 Develop & Deliver

In the Develop and Deliver phases, design solutions were created, refined, and tested iteratively. Regarding system configuration, a proposal for how the process of configuring a system cleaning robots could look was designed and evaluated. Regarding system operation, speculative design concepts on how the system operator could interact with the robot were developed and evaluated. Thereafter, in the final stage of the design process, the focus shifted towards producing and refining the final results that answer the research question for this master thesis. To answer this question recommendations for how to design the interaction with the system of cleaning robots were derived and further exemplified in a scenario.

5.3.1 Hierarchical Task Analysis of the System Configuration Procedure

Since Hierarchical Task Analysis (HTA) is a method for analyzing complex tasks by dividing them into a hierarchy of operations [59], the method was found suitable for describing the future system configuration procedure. The aim of making an HTA was to concretize the data gathered about the work of the system configurator and transform this into a description of the steps required to achieve the final task: a successful integration and configuration of the cleaning robot system. Further, the HTA also aimed to deepen the understanding of what requirements the robot system puts on the system configurator. As described by John [59], the HTA turned out to be an effective means of communication for further discussion around the system configuration procedure and helpful in identifying what tasks will be challenging for the system configurator. Thereto, Benyon [36] argues that a HTA is useful for describing what tasks can be repeated and alternative tasks a user can choose between, which was an important aspect of analyzing the diversified work as a system configurator.

Another TA is the contextual task analysis which includes studying user's current tasks, workflow patterns, and conceptual frameworks and results in a description of current tasks and workflows. Including an understanding and specification of user goals [68]. A contextual task analysis is helpful to understand how a product fits into the user's environment, needs, and in combination with already existing tools [69]. To explore a future workflow, for tasks that does not exist yet the HTA is considered a better alternative as it allows for exploring those future complex tasks and how they tie together rather than studying a context that does not yet exist. HTA was therefore chosen in this case.

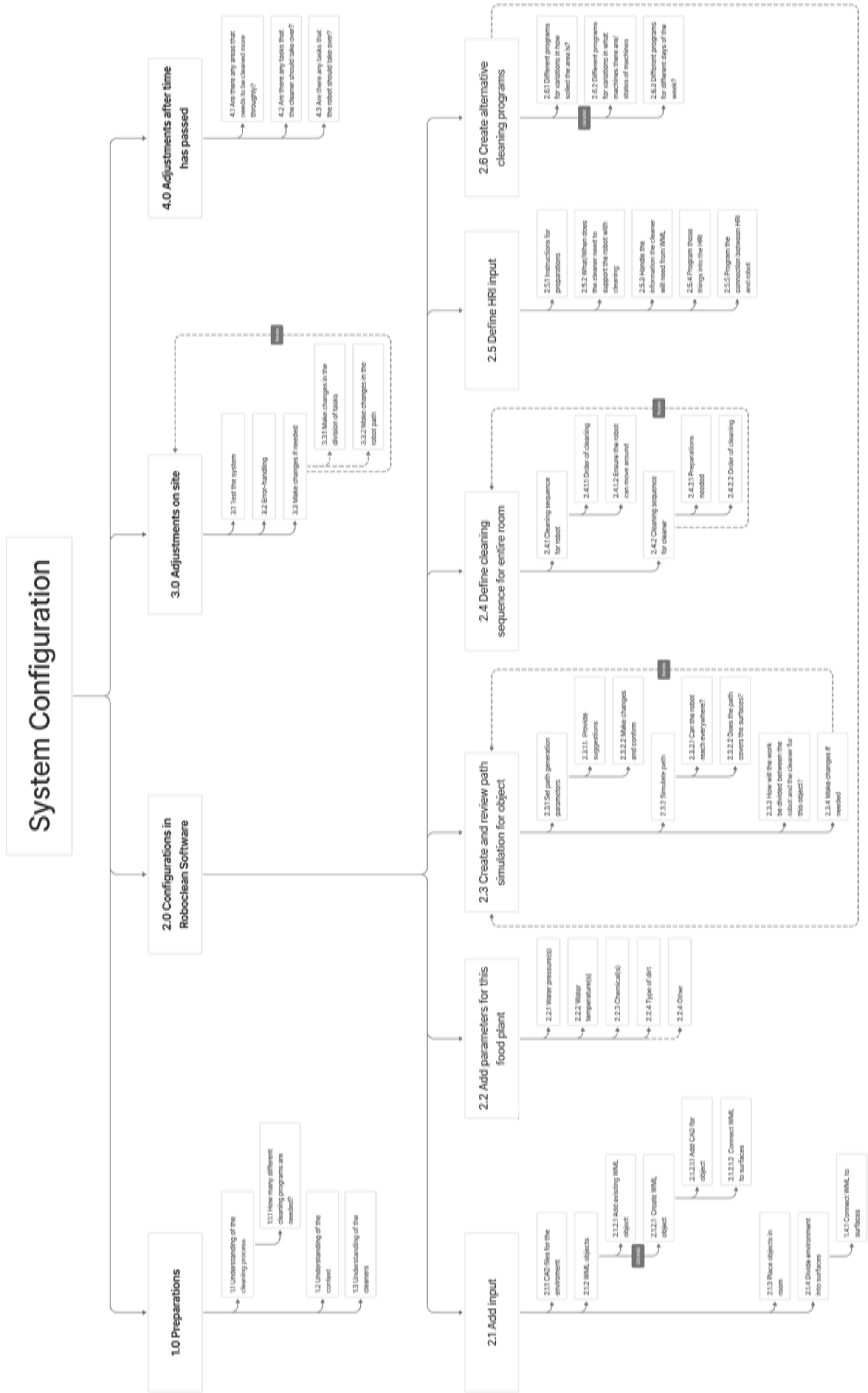


Figure 5.11: The HTA for System Configuration

5.3.2 Evaluation of the System Configuration Procedure

The HTA created to define a suggestion for how the system configuration procedure could look was evaluated with FCC, the robot educator, and the system automation expert. The evaluation aimed to ensure no tasks were missed or redundant, that the procedure followed an appropriate order and the overall likeliness of a procedure following those steps for system configuration of such a system. The evaluation sessions were held remotely and followed a structure where the HTA first was presented step by step, followed by a semi-structured interview. To describe the system of collaborative robots to the participant unfamiliar with the details of it, the System Map, see Figure 5.1, was presented and discussed before presenting the HTA. The questions for those semi-structured interviews can be found in Appendix D. Following this plan ensured that the pre-defined questions were answered, yet it was considered important to have an open discussion and not be locked to only those questions, hence the semi-structured format provided the desired format.

Evaluation with FCC

The two participants from FCC that have contributed to the understanding of the role of a system configurator and the system configuration procedure also took part in this evaluation. Their expertise on the software and its possibilities and constraints was considered to be valuable to ensure the system will be able to handle those tasks as well as to ensure that their view and ours of how the system will work are compatible.

Evaluation with Robot Educator

The robot educator that participated in the interviews earlier in the process contributed with his knowledge also in this stage of the process. His perspective on the configuration process based on his experience of programming and working with robots was a valuable addition to the evaluation.

Evaluation with System Automation Expert

A third evaluation was held with the system automation expert who also participated in the interviews earlier in the process. Thanks to his extensive experience within system integration and configurations, as well as expertise in robotics and automation, contributed with valuable insights.

Findings from evaluation sessions

The participants in the evaluation agreed with the overall procedure presented in the HTA, and found the description of how system configuration could be done probable and trustworthy. Nevertheless, it was noted that changing the order of smaller tasks might be beneficial. Thereto, the overlap and dependencies between the different steps were discussed and the importance of an iterative process was yet again highlighted. Discussions around optimization through defaults, versus manual user input also took place, and the challenges of optimizing the cleaning when taking the work done by robot and system operator into consideration.

The discussions also contributed to the understanding of how much time the different steps are likely to take. The procedure of building up a virtual environment and creating WML objects was considered to take up the absolute biggest amount of time. It was further discussed that reuse of parts of cleaning programs should be possible, as this could shorten the time it takes to build a cleaning program in many cases. Thereto, it was highlighted how difficult it might be to understand the work of the people working with cleaning, the food plant context and all the constraints caused by the environment, yet emphasized how important it is to understand those aspects before starting the procedure of configuring the system in the RoboClean software. Further, it was discussed whether it is likely that the system configuration procedure is carried out by one person, or if it is more likely to be a team specialized in different parts of the procedure. The difficulties to find a person with all those skills today were emphasized, yet the benefits of having the same person to handle the entire procedure were considered to make it worth educating people.

An important outcome of the evaluation was that the title of the system configurator was finally defined and established. The term system integrator had been used to a great extent earlier during the process, and it was therefore discussed what a system integrator really is today and how it relates to the role described for this project. The discussions lead to the conclusion that the role in this project is more about configuration than integration, hence it was decided to name this role system configurator.

5.3.3 System Operator User Journey

A user journey was created to track the future interaction between the system operator, the robot, and the UI connecting them while cleaning. Since user journey is a method for tracking main moments of user interactions by visualizing the involved actors and their tasks and information sent between them [13], this method was identified as fitting for the purpose.

The method was used to visualize the interactions and exchange of information between different parts of the system, aiming to lay a foundation for designing the interaction. Therefore, the user journey includes three different types of events: tasks, interactions, and information flow. The illustration, see Figure 5.12, visualizes the executor and the receiver of these events. Where the clear division of the cleaner, the user interface, and the robot was a strength of the user journey. As well as the differentiation of the tasks, interactions, and information sent between the different players.

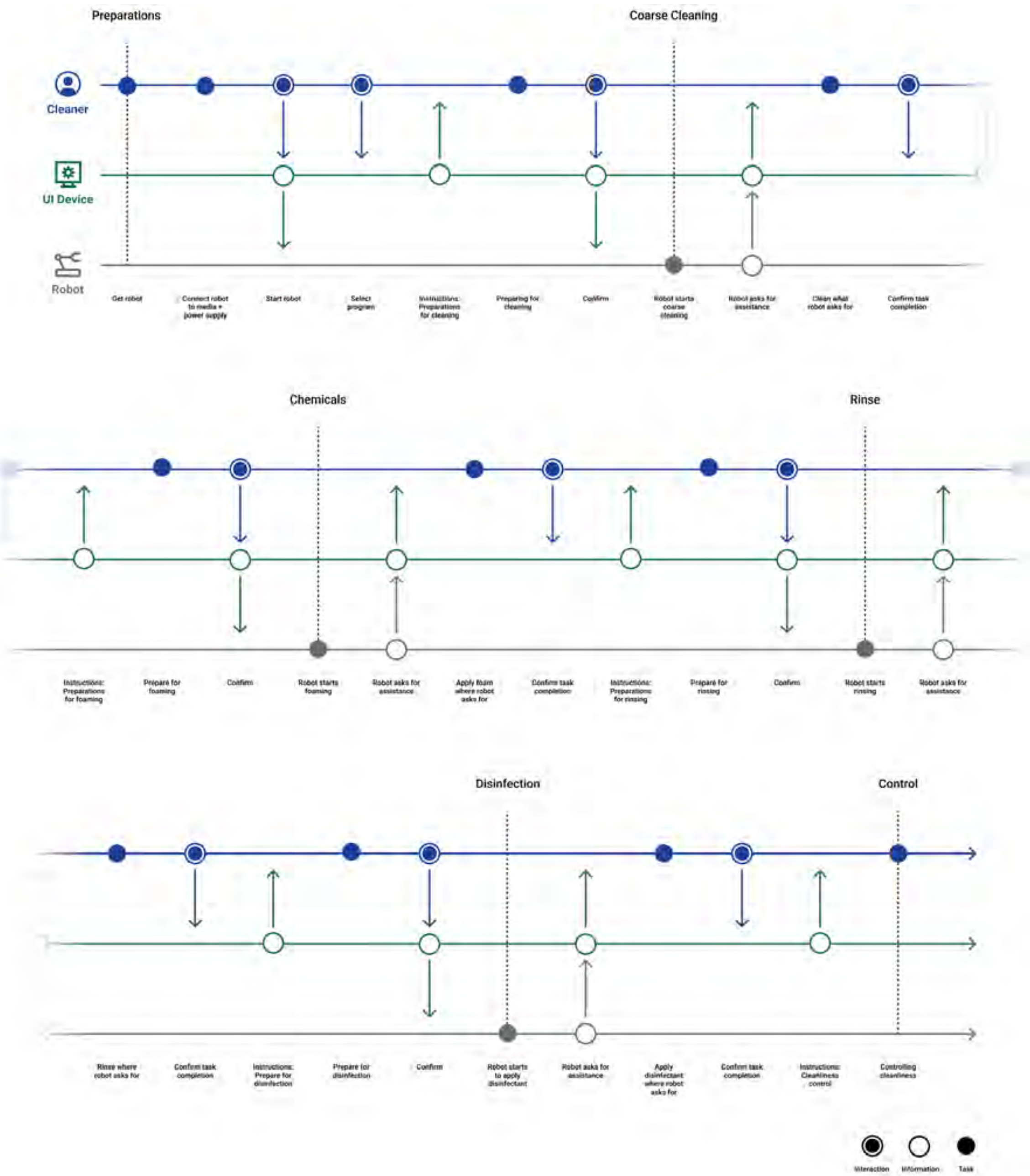


Figure 5.12: User Journey

5.3.4 Developing Speculative Concepts for Interaction Between System Operator and Robot

Based on the findings from the Define phase, exploration of interaction modalities to be used by the system operator took place during the Develop phase. This was done using a speculative design approach with a method for speculative design described by Auger [7] called the ecological approach. This method concerns speculative design for a certain, known context and was therefore identified as a good match for this study. When using this method, the designer must know the context and work with the requirements the specific context sets for the design, and this will in turn create a bridge to anchor the speculative design in a relatable reality. The ecological approach was chosen above other speculative design approaches as it was found the most suitable for what we wanted to explore. Auger [7] for example describes how speculative design also can be used describe an alternative present. However, as the system of cleaning robots does not exist today but might will in the future, exploring the future was found to be more interesting than exploring an alternative current world. The knowledge gathered about the food plant context, the people working with cleaning and the list of requirements during the preceding phases accordingly lay the foundation for the speculations on interaction design.

Auger [7] argues that it remains important for a speculative design concept to be rooted in science and not stray too far away from reality. The technical limitations known today for the robots was therefore taken into consideration when developing the speculative interaction design concepts. Since our goal was to design with consideration to the environment in food plants and the technical limitations that are known today, the ecological approach further supported this aim. However, no such restrictions were applied when it comes to speculations on the interaction mode.

Brainstorming on HRI

A brainstorming session was arranged to ideate on ideas of different ways to interact with a robot. Speculative design concepts for how interaction could take place was encouraged. An open and unstructured brainstorming approach was chosen to support a range of ideas, where anything from written text, to rough or more detailed sketches could be included. Other methods for design ideation also exists, for example braindrawing [61, pp. 64–65]. Braindrawing is a method where sketches is created to quickly generate visual ideas. However, as braindrawing have been found suitable for developing more detailed visual ideas rather that rough concepts, this method was rejected. It was considered important to not limit ourselves to ideate in a short amount of time or for a limited number of ideas. Instead, longer time was considered beneficial as it allowed for more ideas as well as more details of the ideas.

The session started with 5 minutes of sketching ideas on possible means and mediums for Human-Robot Interaction. The results from this session were thereafter listed under the following 7 overarching themes describing interaction styles: gestures, voice/sound, vision, wearable device, portable pocket-sized device, interaction remotely, and interaction directly with the robot. For each theme, a second brainstorming session was held to further examine the possibilities within this category. During this brainstorming session, the pros and cons of each interaction style were listed to explore the possibilities and limitations of each idea further.

Sketching

The brainstorming was followed by a session with rapid sketching to further explore possible ways to interact with a robot. The sketches were done with a speculative design approach, and were thus not limited by what is possible today with current technology. Inspiration was further drawn from emergent technologies and trends within tech. For each of the 7 themes identified in the brainstorming, the researchers spent 5 minutes sketching possible interaction design solutions. This resulted in a total of 68 different ideas on how a cleaner could interact with a cleaning robot while working.

Dot voting

The sketches were evaluated with dot voting. The method was chosen as it allowed for a subjective evaluation where small details of a sketch as well as an complete idea could be brought up and voted on. This was considered a strength for those early concepts compared to a more structured criteria-based evaluation. An alternative to the subjective method of voting on the ideas is a criteria-based evaluation where a decision matrix is used to choose the best ideas from brainstorming. In the matrix the ideas are ranked against a list of criteria [61]. The method requires ideas to be developed enough to rank them against criteria rather than rough sketches and can be difficult to apply for early concepts. However, since a criteria-based evaluation is considered more useful later in the process where more thorough concepts are evaluated, this method was rejected at this stage.

Both participants were given the opportunity to vote for three concepts within each theme, with the votes ranked from one to three. The sum from the ranking of the votes gave a total score for each idea, where 6 points is the highest possible score. Adding the ranked dots opened up for more nuanced voting, and was considered important since only two persons took part in the session. The voting resulted in 7 ideas with a score equal to or higher than 5, see figure 5.13.

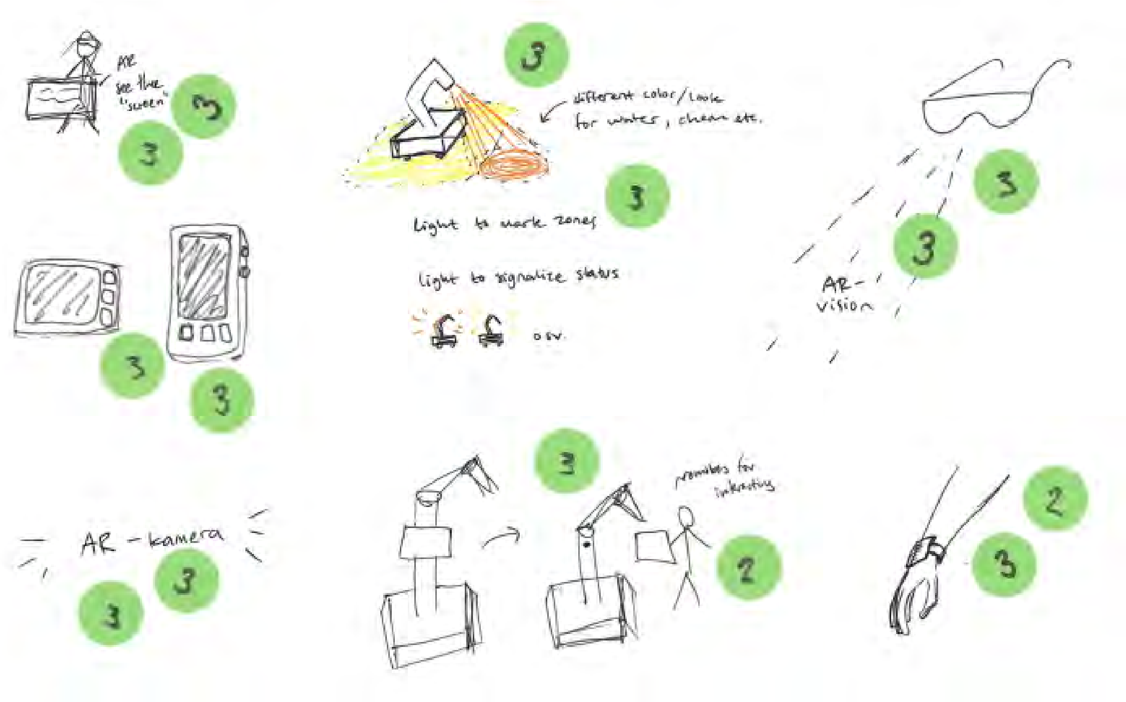


Figure 5.13: A collection or sketches from the brainstorm session with a high result in the dot-voting

Illustrating Refined Design Concepts

The ideas with the highest score from the dot-voting were combined and further refined. The idea of an AR screen was combined with AR glasses, the idea of a mobile device with a screen and physical buttons was combined with an AR camera function and the idea of a detachable device on the robot was combined with the idea of using colored lights on the robot. Finally, there was also the idea of a wrist device that was further developed individually. These ideas were further refined into four design concepts through sketching. The four different design concepts on Human-Robot Interaction and the illustration representing each can be seen in Figure 5.14.

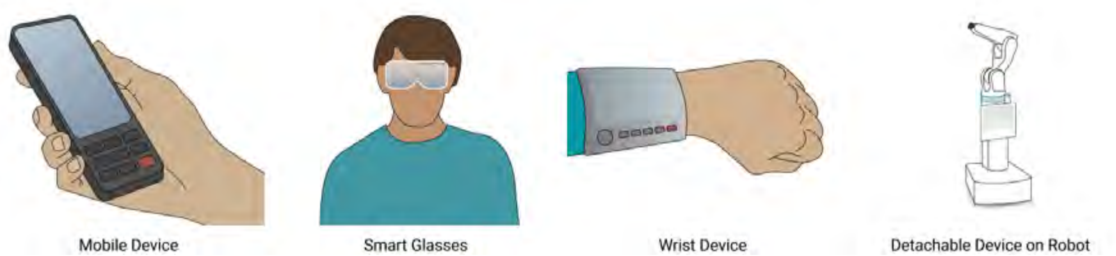


Figure 5.14: The four concepts

5.3.5 Storyboards

In addition to the sketches illustrating the four refined design concepts, there was a need to describe how the interaction between a system operator and a robot could take place using each design concept. According to Malpass [5], narratives be a powerful tool in speculative design as it enables users without significant technical expertise or design experience to emphasize and create an understanding of a futuristic design concept. Therefore, narratives describing interaction with each of the four speculative design concepts were presented with the use of storyboards. Scenario-based design is effective for describing how people will use a system [64, p. 153] and was therefore found to be suitable here. To present the design concepts with storyboards was further motivated as it makes it easy for someone who is unfamiliar with the topic to understand how the concept would work in the context and thereby reflect on possible the strengths and weaknesses of the concepts. Each storyboard follows the same story, describing a few steps of a cleaning procedure. The same storyline was used to avoid bias in evaluation, and also to ensure a simple, equivalent, and reliable comparison of the different concepts. Below is a short description of each of the four design concepts as well as an overview of its storyboard presented. The storyboards can be found in their entirety in Appendix E.

Mobile Device

The first concept is a mobile device with a screen and buttons, similar to a cellphone or remote control. Since the cleaners wear gloves the device has physical buttons and not a touch screen. The cleaners wear the device with them at all times which allows them to control the robot from where they are. Vibrations and sounds are used to notify the cleaner when the robot urges its attention. When the system is informing the cleaner about something in the environment AR is used to describe it to the cleaner, for example, what areas the robot could not reach and what the cleaner therefore needs to take care of.

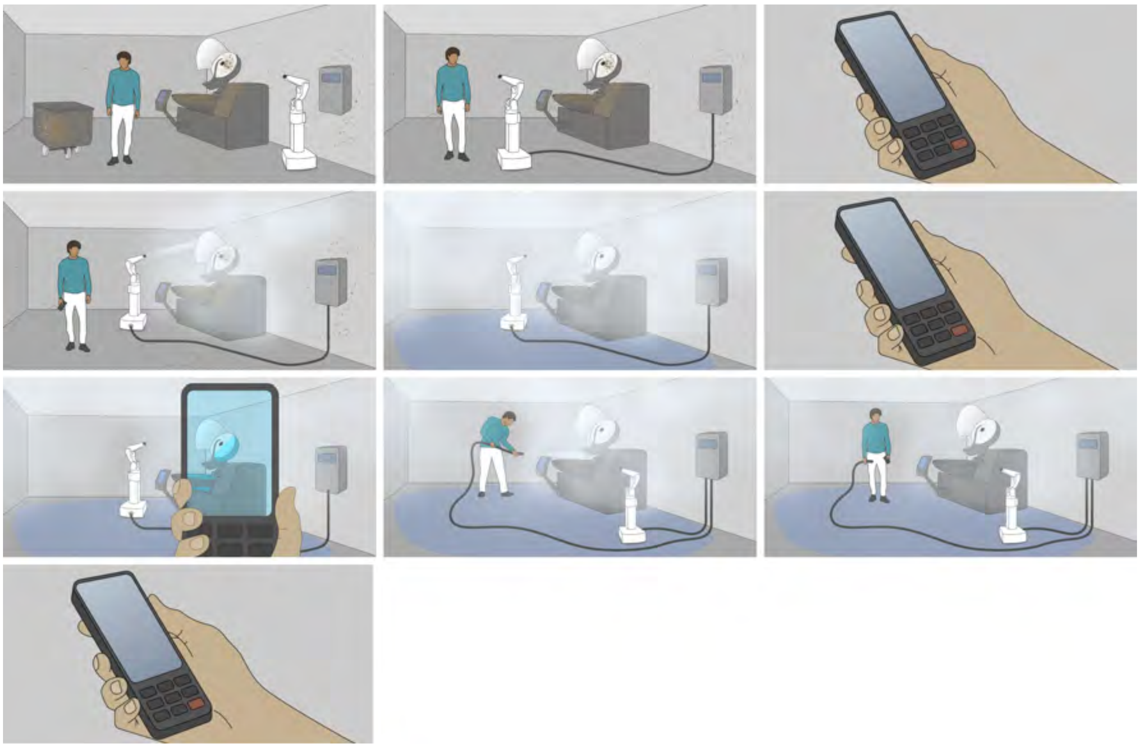


Figure 5.15: The Storyboard for the Mobile Device

Smart Glasses

Today, cleaners are using protective glasses, for our second concept those glasses were developed into a part of smart glasses. The cleaner wears the glasses all the time and can therefore interact with the robot at any point. The glasses use AR to show a menu in front of the user which they can interact with such as if it was a real interface in front of them. To open or close the menu, the cleaner interacts with buttons on the side of the glasses. This is also where notifications are received, displaying a small red light in the corner of the glasses as well as sending out a sound. Similar to the mobile device, the smart glasses also uses AR to describe things in the surrounding to the cleaner.

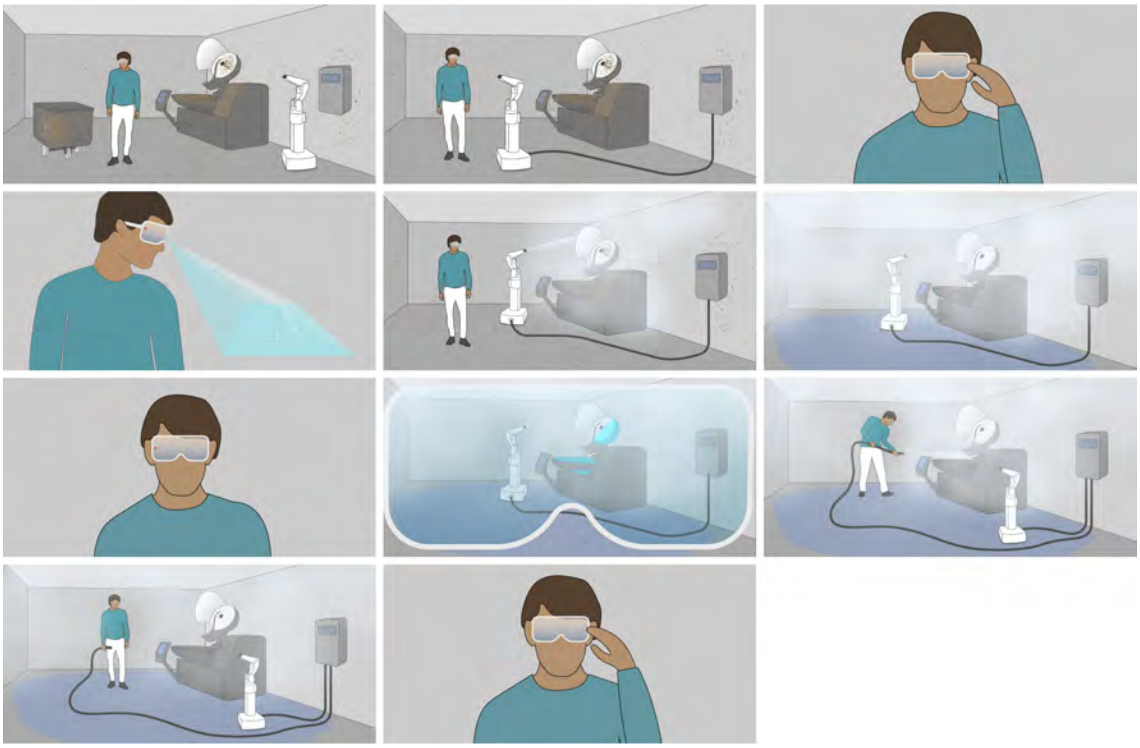


Figure 5.16: The Storyboard for the Smart Glasses

Wrist Device

Another wearable device was developed to be put on the wrist. It is similar to the mobile device with its screen, buttons, and notification style, but differs in its constant placement on the cleaner's arm. This placement interferes with the possibility of using AR to display information in the surroundings, but instead, it shows the cleaner what is left to be cleaned through the CAD models that are in the system.

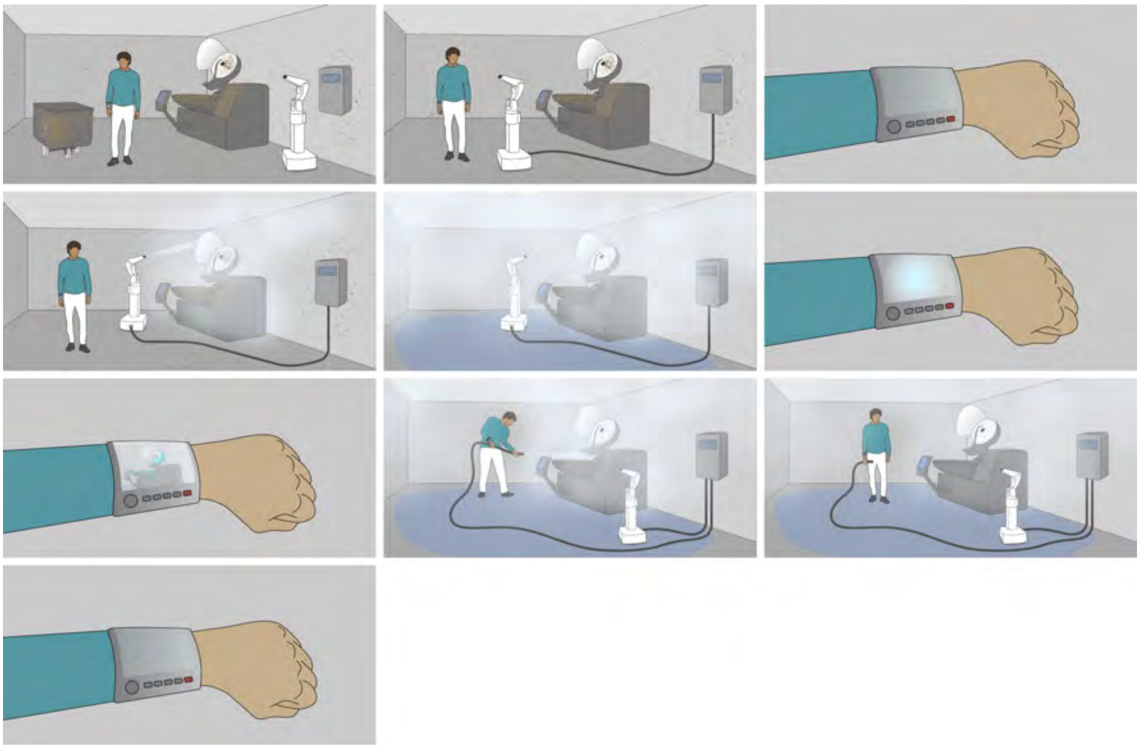


Figure 5.17: The Storyboard for the Wrist Device

Detachable Device on Robot

The last concept is different in the aspect that it is not being carried around by the cleaner. Instead, the concept includes voice interaction in combination with a bigger device that is put on the robot. This device is detachable from the robot for easier interaction but has its main placement on the robot. The cleaners use their voice for simple interactions, such as telling the robot to start cleaning again, and the device is used for more complex tasks that require more information to be sent between the cleaner and the robot. Similar to the other concepts, the device is for example used to describe what needs to be cleaned.

To call for the cleaner's attention the robot signalizes this with a similar sound interaction as the cleaner uses, in combination with a change of light. The robot signalizes its state at all times by a light strip surrounding it, which changes colors depending on what to signalize to the cleaner.

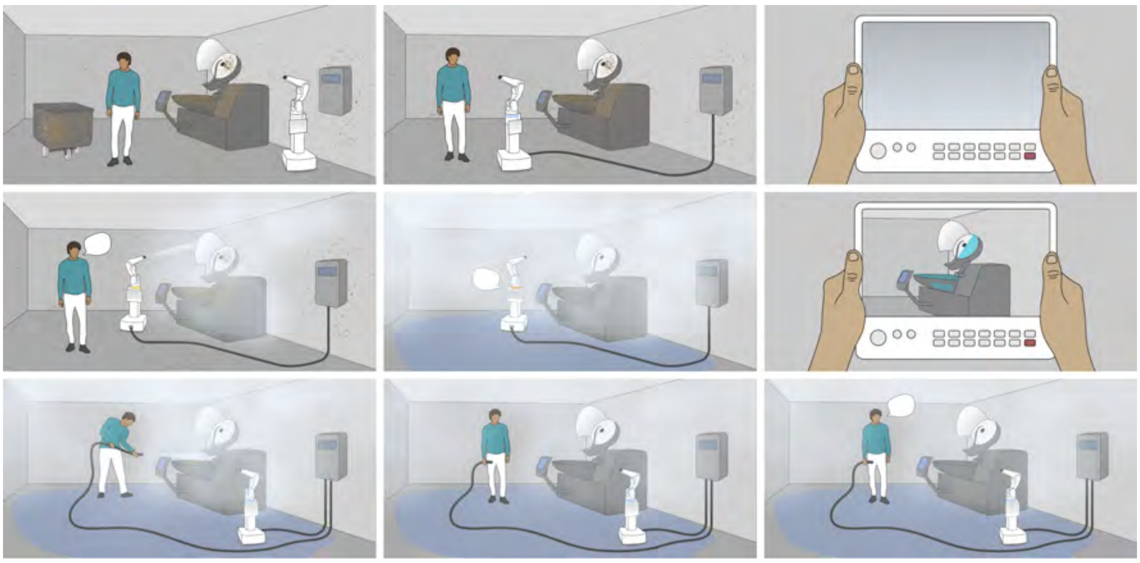


Figure 5.18: The Storyboard for the Detachable Device on Robot

5.3.6 Evaluation of Design Concepts in Focus Groups

To evaluate the designs, two focus groups were arranged. One focus group was held with 6 design students and another with 6 cleaners. The motivation behind choosing focus groups as a method for evaluation was because it opens up for discussion and allows the participants to build on each other's thoughts. Interviews one on one could also have been an optional method for evaluation, but in this case, it was found less suitable as this would exclude the possibility to listen in on discussions between participants.

The choice of participants was grounded in a wish to receive input based on the two different fields of expertise these groups have. The cleaners are the intended key users of the system of cleaning robots and thus play a central part. In addition, they are also experts in food plant cleaning. On the contrary, design students are familiar with the design process and used to design evaluations, and were anticipated to be more prone to be speculative as well as creative when trying to imagine the design concepts. In comparison to the cleaners who are food plant cleaning experts, design interaction design students possess interaction design thinking and creativity. Consequently, the input from the design students and the food plant cleaners were predicted to complement each other with expertise from two different fields.

To enable comparison, the presentations of the design concepts and the following evaluation activities were identical, with only one exception. While the cleaners were asked to rank the concepts based on their own opinion, the designers were asked to do so by relating to the personas. Accordingly, the four design concepts were therefore also shown in the same order during both focus group sessions. The benefit of using the same order was the comparison of the discussions between the two groups became easier, but on the other hand, it is possible that the order in which the design concepts were presented had an impact on the responses. Changing the order could have been beneficial to avoid bias if more focus group sessions were carried out, or if evaluation instead had been conducted through interviews with multiple participants one at a time. However, in this case, the possibility to compare the two focus groups to one another was considered to be more important, and the same order was therefore used.

Focus Group with Designers

Six interaction design students were invited to a focus group with the purpose of evaluating the four design concepts, see Table 5.6. A diverse gender distribution is always to strive for, however this was not fulfilled in this session. Nevertheless, the big number of females in this sessions level out the overall gender distribution of the participants in this study and have the potential to contribute with more perspectives.

The focus group started with a presentation of the RoboClean project and the part this master's thesis plays in it. Thereto, the context of a food plant, and what it is like to work with cleaning in this context was described. The reason for this was to ensure they had an understanding of the users and their work situation before evaluating the concepts. The session continued by going through each storyboard for the concepts and thereafter discussing their initial thoughts about the concepts and what strengths and weaknesses they saw.

ID	Age	Gender
D1	18-29	Female
D2	18-29	Female
D3	18-29	Male
D4	18-29	Female
D5	18-29	Female
D6	18-29	Female

Table 5.6: The designers who participated in the focus group

To ensure the concepts were not only evaluated from their own preferences and perspectives they were asked to evaluate them from the perspective of the personas. The participants were divided into pairs and the three personas were divided between the pairs. Thereafter, they were asked to discuss what they believe their received persona would think about the concepts, additionally, they were also asked to rank the concepts from the perspective of the persona. The questions asked can be found in Appendix F.

The evaluation showed many strengths and weaknesses of the concepts. The mobile device was considered to be simple due to its similarities with technology used today, this was seen as a strength for simplicity of use. But at the same time, the mobile device was predicted to be an outdated type of interaction in the future. A weakness of the concept was that it requires pausing the current task in order to pick up the device and receive information and interact with the device.

The smart glasses were appreciated for their more futuristic design as well as how they are integrated into an already existing product that the cleaners wear. Presenting information in the glasses opens up for a smoother workflow without having to pause current tasks to receive the information, but the importance of the information not being too intrusive was also pointed out. The idea of interacting with buttons on the glasses was negated due to a wish of not putting the hands close to the face in this unhygienic atmosphere. Instead, suggestions on interacting with gestures or voice were brought up. For the mobile concept as well as the glasses, the AR function showing the cleaner where to clean was greatly appreciated, especially for its clear mapping to reality.

The wrist device has the strengths of allowing the cleaner to have the control with them and being accessible all the time thanks to its placement. The information is always near but is not too intrusive. Having the device attached to the writs have the strength of not getting lost or miss placed but the risk of the device limiting the flexibility of the hand was also brought up. The design was described as something that used to be futuristic and something that a long time ago was anticipated to be something used in the future, but which never became reality.

The concept of having a detachable device on the robot was ranked at the bottom for all three personas. The main reason was because of the personas' skepticism towards robots, because of it they were presumed to wish to be at a distance from the robot and to have as little as possible to do with the robot. This concept also opened up many speculations about whether a screen was even necessary.

In general, the buttons on the different devices were not appreciated as they were considered outdated. The limitations on touch displays in this environment were discussed and the possibility of having more futuristic interaction modes such as gestures, speech, or interacting by physically interacting straight with the robot were discussed.

Focus Group with Cleaners

A second focus group was arranged with a group of potential users of the collaborative robot. The group consisted of six food plant cleaners, see Table 5.1. The purpose of this focus group was to evaluate the four interaction design concepts and thereby learn more about their thoughts and opinions on different ways to interact with a robot in a food plant context.

The session was held online and started off with a short presentation of the RoboClean project and our part in this. Continuing, the aim of this session was described in combination with a few pointers that was important for them to consider during the evaluation such as the assistant role of the robot, the speculative aspects of the design, and that they should not be afraid to criticize the designs.

This focus group with cleaners followed the same structure as the one with the design students, accordingly, the questions asked can be found in Appendix F. The only difference from the structure of the previous focus group with designers was that the personas were not used this time. Instead, the cleaners were asked to discuss and rank the concepts based on their own opinions during the final activity of the focus group session.

When reviewing the mobile control, it was brought up how tough screens, in general, do not work very well while cleaning in food plants. Further, concerns about what would happen if the device runs out of battery were also expressed. Also, it was mentioned that it might not be optimal to have to keep a device in your pocket and that they have experienced phones breaking while kept in pockets at work multiple times.

The use of AR for the mobile device as well as the smart glasses was highlighted as a good idea. Regarding the smart glasses, cleaners also expressed that it would feel natural to wear a pair of smart glasses, as they are used to wearing safety glasses already. A benefit of the glasses mentioned was also that they seem more hygienic. However, a concern of breaking the glasses as they might appear fragile was brought up.

The wrist device was not appreciated. The cleaners emphasized the risk of damaging the device when bumping into things while working, and also that something worn on your wrist could be problematic with regards to hygiene. However, one participant also said that it possibly could be a solution if one can make it withstand the wetness and wear.

The detachable device received mixed judgment. Voice command was disapproved by all since they thought it would be difficult and unsafe in the noisy environment. The idea of having to walk over to the robot to interact with it was also disliked by most. In addition, one participant argued that it could be difficult to perceive notifications from the robot. However, one participant emphasized the benefits of always knowing where the device is.

In general, a wish to be able to move the robot manually when needed was expressed several times. A suggestion of an interaction feature alike a joystick was brought up. Further, the cleaners expressed doubts about whether it will be possible to build a robot system like this at all and general skepticism towards the potential of succeeding with the RoboClean Research Project.

Comparison of results from focus groups

When comparing the results from the focus group with the design students and the cleaners the outcome of the sessions afterward citations of all feedback given during both sessions were sorted out. The citations were summarized into shorter comments and divided according to what concept they referred to and from which focus group this comment came. For each concept, these comments were further sorted into positive aspects and negative aspects. The resulting comparisons can be reviewed in the Table 5.7, Table 5.8, Table 5.9, and Table 5.10 below. In general, the designers had more comments than the cleaners, something that can be explained by the fact that design students are used to reflecting on design and providing feedback, whereas the cleaners have limited experience with this kind of design evaluation.

	Cleaners	**Designers**
Pros	Using AR is actually a good idea!	Can interact from a distance
		Intuitive, similar to something that exists today
		Physical buttons are good if they have gloves
		Not intrusive, bring it up when in need for it
Cons	What happens if someone forgets to charge it and the battery dies while cleaning?	Interaction feature of today, but maybe not for the future
	Touch screens do in general not work well in the environment where we work	Physical buttons do not seam like something used in the future
	If you kept it in your pocket you might break it when bumping into things.	Why all those buttons
		Risk of accidentally pressing buttons
		Difficult to hear and feel the notification
		Easy to misplace

Table 5.7: Comparison of feedback from focus groups for the Mobile Device.

Figure 5.19: The Mobile Device

	Cleaners	**Designers**
Pros	We are used to wearing glasses or a visor while working	High tech and cool
	AR in your glasses could work just as well as AR in your phone	Both sound and light for notifications
	Hygienically it's better	No "old boring buttons"
	Feels like the next step, AR menu or holding a phone is not that big of a difference	Doesn't have to pause the work to bring up a device, always accessible
		Good to use something that they wear anyways
		Get the information of what to clean when cleaning, no interruption to get information
		Clear mapping to reality, in real-time
Cons	Looks fragile. They might break if I bump into something?	Hygiene, dirty hands close to the face
		Difficult to find the buttons with gloves
		Maybe annoying to get the same notifications everyday, they will already know from doing this everyday
		Interrupts in the field of vision
		Do they have to wear them all the time?

Table 5.8: Comparison of feedback from focus groups for the Smart Glasses.

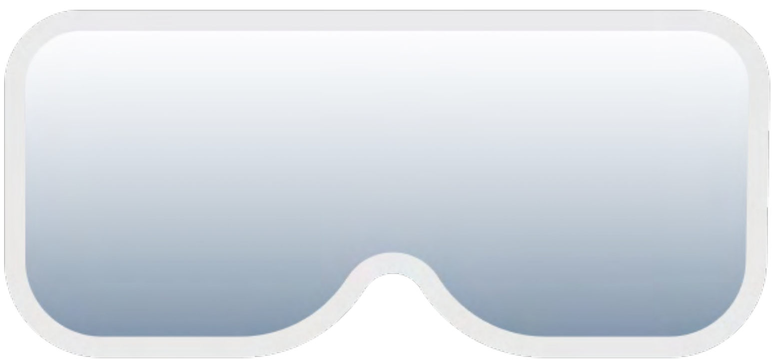


Figure 5.20: The Smart Protective Glasses

	Cleaners	Designers
Pros	Many of us use smartwatches so the interaction seems familiar	Interesting with the mobile device, but not something similar to a mobile
	If you manage to make it 100% waterproof and durable, it could work well	Haptic feedback (if it is on a suitable level)
		Not intrusive, brings it up when in need for it
		Knows where it is all the time, won't lose it
Cons	Doesn't seem hygienic, dirt can get stuck in the device	Risk of limiting the flexibility of the hand
	Seems easy to unintentionally break it if it is on your wrist due to its position.	Why all those buttons
	Is there a risk of the device starting to conduct electricity if it breaks?	Cool in a nostalgic way rather than futuristic
		Show information with an image instead of AR, forces the user to find where it is in reality
		An extra device to wear

Table 5.9: Comparison of feedback from focus groups for the Wrist Device.

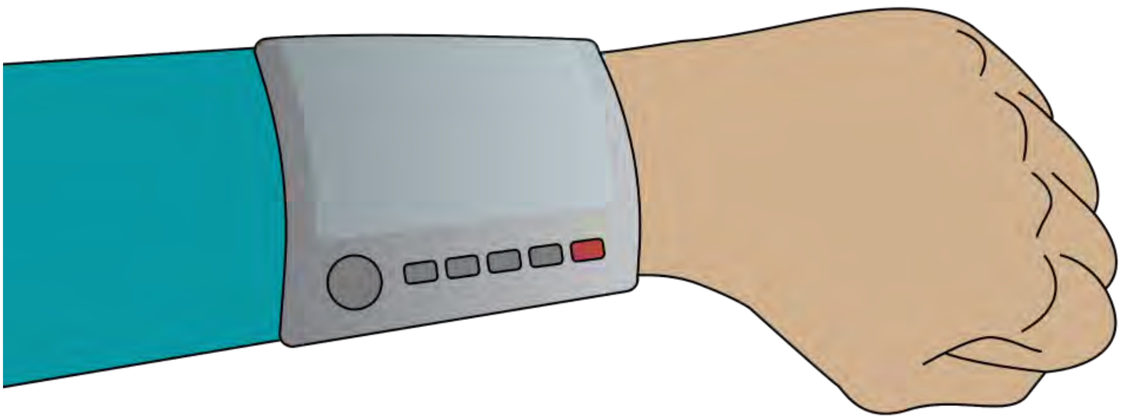


Figure 5.21: The Wearable Wrist Device.

	Cleaners	Designers
Pros	You always know where the device is	Lights to inform the cleaner, not intrusive or requiring a device
		Feels good to not have to wear a device or carry a device around with you
		I like that you interact directly with the robot, not through additional devices
Cons	Voice command will probably not work in the noisy environment	Does not feel safe if you have to be in proximity to the robot to interact with it
	You would have to go back and forth to the robot all the time	Does it need the screen? I only want to talk to it/touch it
	How would you know when the robot is in need of assistance if you are not in the same room?	Will the sound interaction comprehend what is said to a sufficient level? Language and noisy environment
		Don't want to touch a greasy/wet robot
		Interpret that the personas/cleaners don't want to be close to the robot
		Risk of the device being placed in another place than on the robot

Table 5.10: Comparison of feedback from focus groups for the Detachable Device.

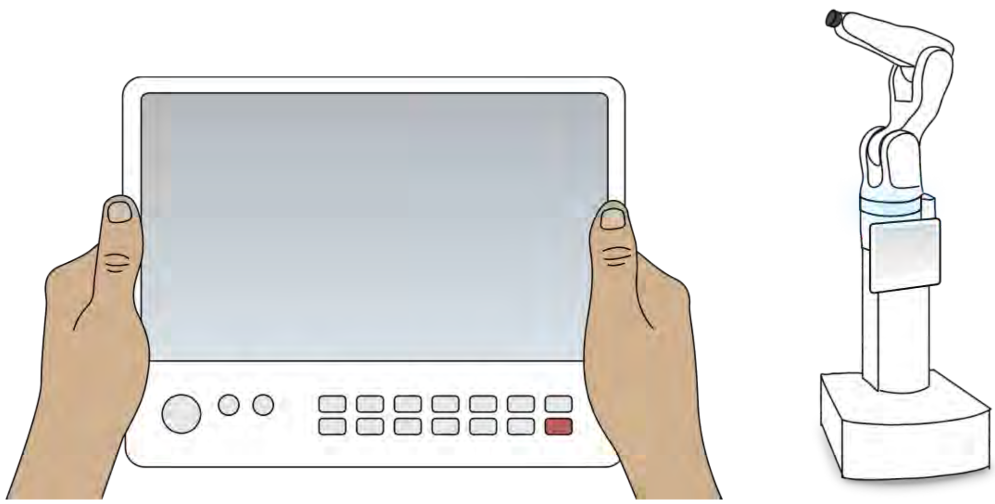


Figure 5.22: The Detachable Device placed on the robot.

Participants ranking of design concepts

The ranking of the concepts from the two focus groups was put together into a graph to get a combined image of how they liked the concepts, see Figure 5.23. The table shows that most participants, 7 out of 9, preferred the Smart glasses. The Mobile device was also a popular concept where 7 out of 9 had it as one of their top two concepts. The Wrist device got ranked around the middle by most persons while the detachable device was ranked in the bottom by 7 out of 9 persons.

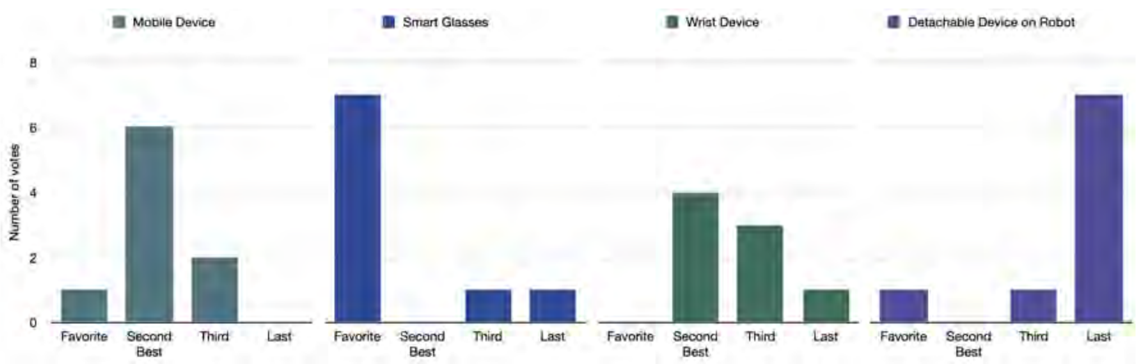


Figure 5.23: Ranking of the design concepts

5.3.7 Pugh Matrix

Based on findings from the two focus groups a Pugh matrix was created to more systematically evaluate the concepts. The criteria for evaluation were based on the list of requirements and those were also weighted based on their MoSCoW classification. Where the rating for the "Must" requirements was multiplied by 3, the "Should" by 2, and the "Could" by 1. The requirements classified as Won´t was removed from the matrix as well as four requirements that relates more to a GUI or details of a final design rather than those early concepts for the interaction mode. The ratings ranged from 1 to 5 according to the list below.

1. Unfavorable performance
2. Less than satisfactory performance
3. Satisfactory performance
4. More than satisfactory performance
5. Excellent performance

The aim of using a Pugh matrix and putting the requirements as criteria was to evaluate how well the different concepts met the requirements that were put up for the interaction. In addition, it also put light on the strengths and weaknesses of the different concepts and showed the areas for improvement. Finally, the result was also used to decide which concept to develop further within the future scenario as part of the final result. Accordingly, the Smart Glasses was found to be the best mode of interaction among these four concepts based on the result of the Pugh matrix, and was therefore selected.

The rankings of how well a device met a requirement were based on findings from the evaluation sessions. Hence, subjective opinions were translated into concrete numbers when creating the matrix. This is something to keep in mind when looking into the resulting pugh matrix. The resulting numbers are to be seen as an indication and not necessarily an absolute answer.

Requirement	Priority	Mobile Device		Smart Glasses		Wrist Device		Detachable Device on Robot	
		Rating	Prioritated Rating	Rating	Prioritated Rating	Rating	Priontated Rating	Rating	Prioritated Rating
HRI **must** provide cleaner with control over the situation	3	4	12	4	12	4	12	3	9
HRI **must** be safe	3	4	12	4	12	4	12	4	12
HRI **must** provide the cleaner with information about what the robot is doing	3	4	12	5	15	3	9	5	15
HRI **must** communicate when and how the robot needs support from the cleaner	3	5	15	5	15	4	12	5	15
HRI **must** be adapted for the environment in a food plant	3	4	12	4	12	4	12	5	15
HRI **must** be possible while wearing protective clothes and equipment	3	3	9	4	12	3	9	4	12
HRI **should** be possible from a distance	2	5	10	5	10	5	10	2	4
HRI **should** be able to give the cleaner notifications from robot	2	3	6	4	8	4	8	2	4
HRI **should** be possible with elementary language proficiency	2	4	8	4	8	4	8	3	6
HRI **should** be designed for users with limited technical background	2	5	10	3	6	4	8	4	8
HRI **should** express robustness	2	4	8	3	6	4	8	5	10
HRI **should** give cleaner information about how to clean	2	4	8	5	10	4	8	5	10
Placement of HRI **should** be accessible	2	4	8	5	10	5	10	3	6
If HRI medium is carried/worn by the cleaner, the comfort of the cleaner **should** be considered	2	4	8	4	8	3	6	5	10
HRI **could** preferably be possible with using only one hand	1	5	5	5	5	3	3	2	2
The design of the HRI **could** support mapping of the relationship between interaction HRI medium and robot	1	3	3	3	3	3	3	5	5
Sum		65	**146**	67	**152**	61	**138**	62	**143**

Figure 5.24: The resulting Pugh Matrix

5.3.8 Design Recommendations

Finally, all the knowledge gathered during this process was about to be reduced to a list of design recommendations. This resulted in 11 design recommendations in total, presented in the Result chapter. These recommendations aim to be a guide supporting User Experience when designing for interaction in the future of the RoboClean Research Project. As the two main user groups, referred to as system configurators and system operators, interact with the system of robots in different ways at different times, the recommendations were divided into two tables, see Table 6.1 and Table 6.2. The first table describes design recommendations for interaction during configuration and the second during operation. Accordingly, there is one set of recommendations for the system configurators who primarily interact with the system during set up in a new food plant and another set of recommendations for the system operators who primarily interact with the system while it is running in a food plant.

5.3.9 Future Scenarios

Finally, two scenarios was put together. One describing system configuration and one for system operation. The decision to use scenario-based design was grounded in the potential of using this method to exemplify how the design recommendations could be fulfilled. As described by Boy [64, p. 153], scenario-based design is effective for changing the focus from defining functional specifications to describing how people will use a system to accomplish tasks and other activities, hence this was considered to fit our aim.

The system configuration scenario describes a system configuration process from initiation to testing on site, where the interactions with the RoboClean Configuration Software is the main focus. This narrative is based on the final version of the HTA and the findings from evaluations of the HTA with system configurators. The system operation scenario describes a cleaning shift in a food plant where a system operator works together with a cleaning robot. Within the scenario, a refined speculative design concept is also presented. This refined speculative design concept entails Human-Robot Interaction through a pair of AR safety glasses, and was created based on the findings from the focus group evaluations and the result of the Pugh matrix. The focus group evaluations and the Pugh matrix both indicates that the concept of Smart Glasses is the one with most potential among the four concepts that was evaluated. Therefore, this concept was chosen and further refined into a final speculative design concept for Human-Robot Interaction.

Sharp et al. [4, p. 426] describe how a combination of images and text provides stakeholders with more details and helps them imagine what it would be like to interact with the design. The combination of text and illustrations was therefore considered to be an effective way of presenting this scenario, where text describes the complex details and illustrations support the understanding of how this could take form. The scenarios of how the interaction can take form can be found in the Results, in section 6.2. To ensure the scenarios accord with the direction of the development of the RoboClean Research Project the scenarios were sent out to ABB and FCC. This led to some minor changes in the scenario.

6

Result

This chapter describes the results, including interaction design recommendations and illustrated scenarios describing how a system configurator and a system operator could work and interact with the RoboClean system in the future.

6.1 Design Recommendations

This section presents 11 design recommendations for how interaction with a system of cleaning robots should be designed. The recommendations are an outcome of this master's thesis formed by the insights gained throughout the process, from the early observations to the final evaluations. Hence those recommendations aim to answer the research question stated below.

How should the interaction with a system of cleaning robots be designed to support the users' experience during configuration and operation?

6.1.1 System Configuration Design Recommendations

The table below contains a summary of the design recommendations for interaction with the system of cleaning robots during configuration. In other words, these recommendations refer to the interaction between a system configurator and the RoboClean Configuration Software while setting up the system of robots to work in a particular food plant. The design recommendations are further described and argued for below.

	Design Recommendation	Description
DR 1	**Provide optimized defaults, but allow for changes**	Solutions optimized by the software should automatically be presented as default options, but the user should have to possibility to make changes manually.
DR 2	**Support the user with decision making**	Support the user with sufficient and relevant information, as well as with guidance and suggestions, when making decisions on how to put together a cleaning program. The RoboClean Configuration Software should help the user build programs that promote effectiveness, efficiency, and sustainability.
DR 3	**Support reuse of parts from other cleaning programs**	The different parts of a cleaning program should be possible to reuse again in the same cleaning program as well as in other cleaning programs.
DR 4	**Provide the user with an overview, but allow examination of details**	The user should be able to overlook the overall cleaning procedure when analyzing a cleaning program. Nevertheless, it should also be possible to examine the tiniest details of the cleaning program.
DR 5	**Encourage a Human Centered Design approach**	The work by system configurators will directly impact the system operators' User Experience. To support a good User Experience for system operators, the RoboClean Configuration Software should support a Human Centered Design approach during system configuration.

Table 6.1: Design Recommendations for interaction during System Configuration

DR 1. Provide optimized defaults, but allow for changes

The aim of the RoboClean Research Project is to optimize the cleaning procedure in terms of efficiency, effectiveness, reliability, and sustainability. With the use of algorithms, the RoboClean Configuration Software will generate mathematically optimized robot paths and cleaning programs. To achieve the goal of optimization of the cleaning procedure, it is therefore recommended to encourage the user to make use of these optimized solutions by providing these as default options. For example, when generating a robot path for how to clean a machine, the RoboClean configuration software should always suggest what, according to the software's calculations, is the optimal option as default.

Providing default values is a powerful tool to speed up the configuration process and guide the users towards a good result. People commonly stick to the default solution, and it is therefore of great significance that the software provides the best possible option as default. Default options should however only be used if an optimized option exists. Tognazzini [70] describes that default options should be "intelligent" and responsive. They should only be provided if it is possible to calculate what is optimal, and only if it is faster to review the default than entering the desired choice manually.

> *"Purely mathematical aspects like time and such things, would be great if you could get all of that automatically"* *
>
> ***S2***

The process of building cleaning programs will and should not be completely autonomous. Users should always be given the possibility to change a set default value [71]. The default suggestions should not be locked in, but rather should they be seen as guidance and work as a support to the configurator, who should retain the possibility to manually change the suggested settings if needed. The complex environment with its uncertainties and tasks partly carried out by humans puts demands on the system that the algorithms cannot handle completely (yet).

In addition, it might not always be obvious what option is optimal taking all the four factors of efficiency, effectiveness, reliability, and sustainability into account. The software will make a suggestion striving to optimize all four factors, but there might be cases where extra emphasis should be given to one of them. Hence, the configurator must be able to make changes to the suggestions from the software to ensure it is a solution that fits the unique settings.

DR 2. Support the user with decision making

Bragança et al. [15] emphasize the importance of planning tasks in a careful and exact manner in contexts where humans and robots collaborate. When planning work and assigning tasks to humans and/or robots, the individual limitations of each part must be taken into consideration. Furthermore, one of Kadir et al's. [9, pp. 608–609] key design factors when developing collaborative robots for industrial work systems is *Clear division of tasks.* To plan the division of work between the operator and the robot is part of the work as a system configurator, but making good decisions as a system configurator requires knowledge in multiple fields, such as cleaning and robotics. The RoboClean Configuration Software should therefore give the system operator the best possible conditions for making well thought out decisions. In addition to suggesting the optimal option whenever possible, the software should provide the user with all relevant information to base decisions on, and present this information in a clear and comprehensible way.

*Quote translated, originally in Swedish

The design principle of Anticipation by Tognazzini [70] describes how a system should provide the user with all the information and tools needed to successfully complete each step of a process. Tran [72] further describes the importance of information design to help users make informed decisions and accomplish their goals. Providing users with information gives the users context and a clue of what would be a good decision. The information must not be overwhelming or confusing but presented in a clear way to the users.

Examples where the system configurator needs this support from the software, are when analyzing a generated path for a specific object, or when analyzing the simulation of a complete cleaning program. In these situations, the software must provide the user with information that is relevant for the assessment of the result. For example, it will be of interest to know the use of resources like time, power, water, chemicals, and disinfectant. In addition, it will also be of interest to know to what extent a robot can complete the work under current settings, and how much support from a human system operator is needed.

DR 3. Support reuse of parts from other cleaning programs

Food plants are not standardized, rather the opposite. They come in different sizes with different equipment. Nevertheless, some factories share similarities and may for example have machines of the same kind. This is why the library of WML objects is necessary, but in addition to reusing WML objects from a library, it could also be beneficial to reuse entire parts of a cleaning program, for example, a cleaning sequence with a generated robot path for one or multiple WML objects.

A cleaning program in the RoboClean Configuration Software is built up object by object, and this modularity should be preserved for cleaning programs also later on in the system configuration process. The system configuration should be able to go back and make changes to a specific object, and the software should also enable the reuse of parts like robot paths from old cleaning programs and bring these into new projects.

> *"Maybe, one can reuse a part of the program from another step in the cleaning procedure and just change some small parameter."* *
>
> ***S5***

Reusing parts of cleaning programs would be particularly helpful when building new versions of cleaning programs in a food plant with available preexisting cleaning

*Quote translated, originally in Swedish

programs. Instead of re-generating all paths from scratch, parts of the old cleaning programs could be reused and modified whenever necessary, to shorten the configuration process. Reuse could also be helpful with path generation for the same type of machine in a different food plant.

It would also be beneficial if the final product, that is a compiled cleaning program for a food plant, is modular. This would facilitate updates of cleanings programs since the system configurator in that case only would need to update the modules concerned and not have to regenerate the entire path for the food plant. Updates and changes to the cleaning program after some time is likely, it should therefore be easy to make these changes.

> *"The process of configuring a system could be flexible enough to load an existing program and then make it easy to change some parameters, remove a step of cleaning or two, and then churn out new [Rapid] code."* *
>
> ***S5***

DR 4. Provide the user with an overview, but allow examination of details

A cleaning program can be compared to a chain of cleaning tasks divided between human and robot. Every task is a link in the overall cleaning program, and every task thus affects how the cleaning program performs as a whole with regards to the optimization of efficiency, effectiveness reliability, and sustainability. To support the user in the analysis of the cleaning program and promote optimization during the configuration, the system configurator must be able to examine the cleaning program as a whole as well as down to the smallest detail.

It could be of interest to study a robot path for a specific machine in detail to examine, for example, whether it is beneficial to change some cleaning parameters and have the system operator do a bigger portion of the work on this machine. Meanwhile, the system configurator must also be able to gain an overview of the entire cleaning process from preparations to completion to understand, for example, how the cleaning program reduces the consumption of resources. It is thus important that the RoboClean Configuration Software supports the user in understanding the cleaning program at all levels, from the tiniest detail of how a specific area is cleaned, to show a cleaning program performs as a whole. A configuration software should ease the process of analyzing details as well as getting an overview of an entire program.

*Quote translated, originally in Swedish

> *"If you need to make a new simulation or new path planning, or any change that requires an overall understanding of the whole [cleaning program], you will go back to IPS [i.e. the RoboClean Configuration Software]"* *
>
> ***S5***

DR 5. Encourage a Human Centered Design Approach

During a system configuration process, tailored cleaning program(s) are created to adapt the system of cleaning robots for a unique food plant and the users operating in this environment. One of Kadir et al's. [9, pp. 608–609] key design factors when developing collaborative robots for industrial work systems is *Understanding existing processes*, motivated by the need for an in-depth understanding of existing work systems. Further, when interviewing system integration experts, great emphasis was put on understanding the users, their tasks, and the environment. The configuration process can thus be compared to a design process where a product, in this case, the cleaning program, is created based on user needs and requirements.

As the result from the configuration process will direct the work while cleaning, the result of the configuration will impact the User Experience of the system operators. According to Benyon [36, pp. 5, 22], the practice of User Experience is in general done with a Human Centered Design approach. Further, Prati et. al. [12] argues that the application of UX design methods and consideration of Human Centered Design aspects promotes an overall improved Human-Robot Interaction. To ensure that conditions for good User Experience are created, the application of Human Centered Design during the configuration process should therefore be encouraged by the RoboClean Configuration Software.

Applying a Human Centered design approach means putting emphasis on the importance of understanding the system operator, the cleaning tasks, and the food plant context in a system configuration process according to the ISO standard [39], and the RoboClean Configuration Software should support this understanding. For example, for a system configurator to be able to assess what is a good division of work between human and robot, the system configurator must have an understanding of the different work tasks. The software should support this understanding through descriptive and detailed simulations that enable the system configurator to immerse into the result.

*Quote translated, originally in Swedish

> *"I have to understand what the situation looks like. They [the users] do not know what they want, I have to understand it for them. One must understand the needs of people." **
>
> ***S3***

> *"There will be a digital twin for almost the entire room, and that introduces some serious requirements. It is easy to overlook and miss out on details that you just recognize automatically without paying much attention." **
>
> ***S2***

It further means that system operators and other end users of the system should be involved during the system configuration, in development phases as well as during evaluation according to the ISO standard [39]. By involving the system operators in the system configuration process, needs and requirements, as well as flaws in the cleaning program, can be detected earlier and more easily. The software should support this by making simulations understandable also for users with no experience with the software.

A Human Centered Design Approach also means developing the result iteratively [39]. Iteration is of great importance when developing complex systems, and an iterative work process can make it easier to find and correct flaws and other areas of improvement [73]. Further, it can ease development in projects with high levels of complexity, uncertainty, and change. To continuously evaluate and refine while building a cleaning program is therefore necessary. Hence, it is of importance that a software support an iterative process. This goes for every part of the configuration process, from creating the first paths to testing and modifying the final cleaning program in reality.

6.1.2 System Operation Design Recommendations

The table below contains a summary of the design recommendations for interaction with the system of cleaning robots during operation. In other words, these recommendation refers to the interaction between a system operator and a cleaning robot while cleaning in a food plant. After the table, descriptions, and argumentation for the design recommendations follow.

*Quote translated, originally in Swedish

	Design Recommendation	Description
DR 6	**Adapt Human-Robot Interaction for the work environment**	The environment in a food plant is often noisy, wet, and dirty. While working, the system operators wear protective equipment and clothing. Additionally, the context introduces requirements for hygienic design. Any interaction designed for this user group must be adapted for usage under these circumstances.
DR 7	**Adapt Human-Robot Interaction for the work tasks**	The mobility or flexibility of users shall not be limited. The risk of accidentally interacting with the system or breaking something shall be minimized. Basic interaction should not require the user to make use of both hands.
DR 8	**Adapt Human-Robot Interaction for the target user group of system operators**	The system of robots should make use of multiple ways to communicate information. For example, design with considerations to a user group with limited technical experience and varying language skills. Also, make use of visual representations of the environment when conveying information relating to it.
DR 9	**Enable remote Human-Robot Interaction**	The system operators will not always be in close proximity to the robot while working. Therefore, exchange of information should also be possible remotely. Further, interaction needs to be possible remote from as well as next to the robot.
DR 10	**Design for a seamless shift from cleaning to interacting with the system**	The transition from working with cleaning to interacting with the robot should be smooth. The interaction shall not interrupt the user and require their attention immediately. Information shall always be accessible but not too intrusive.
DR 11	**Design for perceived control and safety**	The user must feel safe and in control of the robot at all times. It should be easy for users to foresee what the robot is doing and what it is about to do.

Table 6.2: Design Recommendations for interaction during System Operation

DR 6. Adapt Human-Robot Interaction for the work environment

Designing for the context is an important aspect of User Centered Design. Chu [8] discusses how the context prescribes peoples' needs and how the User Experience of a product is highly dependent on the context in which they are used. When designing for interaction, one must take the conditions under which the product is used into consideration for a successful implementation.

The environment in a food plant puts high demands on any product that is to be used there. First and foremost, any equipment that is brought into a food plant must meet the hygienic requirements. Any medium of interaction must therefore be hygienically designed, and any method for interaction must not entail any risk of contamination of the environment. During an interview, the importance of hygiene was expressed in the following way by one of the cleaners:

> *"We are working with food, so hygiene is extremely important!"* *
>
> ***C4***

Further, lots of dirt can be spread around the food plant, and cleaning with water makes the humidity high. Water, dirt, or chemicals might splash on any object inside the room while cleaning. Any medium of interaction must therefore be resistant to the wet and dirty environment, also over time. Interaction must further be functional also when wet. A cleaner from the focus group said the following when discussing interactions in a food plant:

> *"Touch screens don't work very well in our work environment."* *
>
> ***C1***

Machines running in cleaning mode, as well as the sound from spraying water or chemicals, makes the environment noisy as well. To protect their hearing, the cleaners often use hearing protectors while working. Hence, this puts high demands on any interaction making use of sound. Thereto, the cleaners wear rubber gloves which limit their ability to interact with precision.

*Quote translated, originally in Swedish

DR 7. Adapt Human-Robot Interaction for the work tasks

To clean in a food plant is a physically demanding job. Over time, many cleaners describe how their bodies have taken damage from the work. The physical load is also one of the most common negative aspects brought up by cleaners when asked about their opinions about their profession. It is therefore important to design the interaction with the system of robots in a way that does not make the job more demanding, but rather reduces the load for the future system operators.

> *"The work is tiring. It gets heavy. You get lots of problems with your back, shoulders, wrists, etc."* *
>
> ***C7***

The system operators' mobility and flexibility will also be of importance while cleaning, and it should therefore not be limited by any medium of interaction. For example, the system operators must be able to stretch, climb and bend down to reach all of the corners of the different machines. As described during interviews with cleaners:

> *"It is physically demanding. You move a lot, up and down, climbing on machines and crawling on the floor."* *
>
> ***C10***

> *"It is quite annoying to have a phone on you while working. You hit things. Multiple phones have broken here while kept in a pocket during cleaning."* *
>
> ***C1***

The cleaners are always in motion and the risk of bumping into things is big. A future medium of interaction should not risk breaking in such situations. Neither should the system operators risk accidentally interacting with the system while moving around.

Since the system operators will be cleaning, they will be holding a hose for the majority of the time. Therefore, interaction with the system of robots should not require the system operator to put the hose down just to interact with the system. Hence, frequent interactions while cleaning shall not require the system operator to make use of both hands.

*Quote translated, originally in Swedish

DR 8. Adapt Human-Robot Interaction for the target user group of system operators

Understanding the user group is a key to understanding how to design for a good User Experience [4]. Wilkinson et al. [18] investigated how to design for users without robot expertise interacting with a system of assistive robots. They present *Understandable* and *Accessible* as two main design principles. Adapting the interaction for the system operators by making it understandable and accessible will thus be crucial. Working with cleaning in food plants today does not require any significant level of technical knowledge, and it should not do so when introducing a system of cleaning robots either. The interaction between human and robot should be adapted for the people who are working with cleaning in food plants today, and not the other way around. Wilkinson et al. [18] emphasize that a design should enable people with different physical and cognitive abilities as well as with the different levels of experience with robots to interact with it.

Nielsen [74] advocated for the importance of designing systems that speaks the users' language. The design should reflect the real world to make interaction easier for users to learn. In general, cleaners today have little or no academic background and minimal experience with advanced technologies like robotics. Among the user group of system operators, a significant variation in language skills was identified during the user studies. A majority of the cleaners that participated in the interviews did not have Swedish as their native language. Therefore, the solution shall make use of a clear and easily understood language, where any unnecessary complex formulations should be avoided.

In line with design recommendations for accessibility described by Friedman and Nelson [75], images and icons should be used to convey information along with spoken or written language. Also, the expressions of these should be tailored for the target user group of system operators to support a smooth and correct interpretation of information. Since the system operators will perceive and interpret information differently, making use of multiple ways of communicating information is also a way to support the transfer of information from the system of robots to the user. A text can be used together with an icon. Sound could be complemented with visual information. Haptics and colors are other ways to communicate with the user.

The system of cleaning robots will have lots of information and instructions to share with a system operator. Most of this information concerns something inside the food plant, for example, information on what machines have been cleaned by the robot and instructions on where the system operator has to clean to complete the work. To convey information about the surrounding environment, visual representations of it can be used. Nielsen [74] suggests that it is preferable that the user can recognize something, rather than forcing the user to try to remember it. In other words, the user can recognize a meat grinder machine and its position within the food plant from an image, but if only the label "meat grinder machine" is provided this forces the user to try to remember what machine this is and where it is located.

During the evaluation of concepts with the designers, the difficulties of describing things in the surroundings with words were discussed.

> *"Sometimes it can be difficult to see where the machine has been cleaned. Using AR so you can see these areas could be quite good then."* *
>
> ***C1***

DR 9. Enable remote Human-Robot Interaction

Cleaners are constantly moving while working today, and this will also be the case for the future system operators. As a result of this, the distance between the system operator and the robot will vary a lot during a work shift. Sometimes, the system operator might work side by side with the robot. Other times, the system operator might work in a completely different room.

During the focus group with cleaners, 5 out of 6 participants expressed that they disliked the idea of having to walk over to the robot to interact with it. One participant said the following quote to motivate his position:

> *"No one likes the idea of having to be next to the machine [to interact with it], because then you would have to run over there all the time and you have your own tasks to do. You would lose control over the robot."* *
>
> ***C2***

Interaction between human and robot should therefore be possible remotely to support this need for mobility, without excluding the possibility to interact in close proximity.

*Quote translated, originally in Swedish

DR 10. Design for a seamless shift from cleaning to interacting with the system

When users are provided with information, the way this information is communicated should not be too intrusive nor distract the user from the surroundings, according to Franco and Cabra [76]. During the focus group evaluation with the design students different ways of notifying the users were discussed and alternatives that are notable but not intrusive was brought up, for example, one participant described how lights could be used:

> *"It doesn't have to be something that persists on your attention, it can just be like a small shift in the lights, so now [i know] it is done"* *
>
> ---
> ***D2***

As the user will work on their own tasks in parallel with the robot they shall not be interrupted and forced to pause their own work immediately. They should receive the information but not be forced to act on it right away. The information should always be accessible but never too intrusive for them to continue what they are doing. The importance of not interrupting the user to tell them something was highlighted by one of the design students:

> *"You don't have to break your workflow to know what is happening"* *
>
> ---
> ***D3***

Providing users with information in a way that achieves a high awareness of the information without disrupting or being annoying is a difficult task. When information is displayed without supplanting the current task of the user, a low level of intrusion is achieved. In such a situation, the user can decide whether to immediately act on the information or finish the current task first. This results in a balanced experience of intrusion and awareness of the information [77].

Thereto, the interaction shall also be designed to create a smooth transition from working to interacting with the robot for the cleaner. This was also something highlighted by one of the design students:

*Quote translated, originally in Swedish

> *"It maps directly onto the reality, and he doesn't have to go through the extra step of picking up a device or search through a display. He gets the information needed straight away as well as direct feedback."* *
>
> ***D4***

DR 11. Design for perceived control and safety

Even though the cleaning robot will work autonomously, the system operator should be in control over the system of cleaning robots at all times while cleaning in a food plant. However, it is not enough to just provide the system operator with full control over the robot, the system operator must also experience that he or she is in control. As stated by Zafari and Koeszegi [29], a low level of perceived control in collaboration with an autonomous robot can lead to a negative attitude towards the robot. On the contrary, a high level of perceived control is found to mitigate negative attitudes towards robots and foster social relationships between humans and robots. Similarly, a study by Akalin, Kristoffersson, and Loutfi [30] showed that when participants in their study felt in control, they were also comfortable and trusted the robot. Designing for a high level of perceived control by system operators when interacting with the system of robots is therefore of great importance to achieve a good User Experience.

Safety is another critical factor when designing for interaction between robots and humans, as stated by Bartneck et al.[31], and for the RoboClean system of robots, safety is a non-negotiable prerequisite. However, it is not only the actual safety that affects the User Experience but also the user's perception of safety and level of trust. When Chowdhury et al. [14] studied User Experience driven design in relation to Human-Robot Interaction, he listed safety and trust as one of the most important UX goals. It is of great significance that the system operator will experience the interaction with the system of cleaning robots as safe [31][30]. To achieve acceptance of a robot from industry workers like the system operators, perceived safety is crucial[31]. It is therefore a recommendation to not only design an interaction that is safe, but also an interaction that feels safe. The importance of feeling safe and in control in order to feel safe was emphasized by one of the design students:

*Quote translated, originally in Swedish

> *"An advantage of having a remote control that is separated from the robot is that it feels like an extra security measure... I can stop it [the robot] from where I am"* *
>
> ***D4***

In order to feel safe and in control, the system operators must be able to understand the robot's behavior and foresee what the robot is about to do. Kadir et. al. [9] argues that *Visualization of Robot's Path and Workspace* is a key design factor when developing collaborative robots for industrial work systems, as this can make human workers feel safer in proximity to collaborative robots. The users should be able to foresee the robot's actions, and a significant factor in achieving a good User Experience will thus be to design for visibility of system status. Nielsen [74] describes the importance of keeping users informed about what the system is doing to make them feel in control and build trust. As insufficient information frequently equates to a feeling of lack of control and trust, it will be important to provide the system operator with appropriate information and feedback from the system of robots to support perceived control and safety.

> *"How can I know that it [the robot] won't spray on me?"* *
>
> ***C2***

6.2 Future Scenarios

To exemplify how those recommendations can be fulfilled in a design, a suggestion for a design solution was created and presented in two scenarios. The scenarios follow the procedure of configuring the system as well as when the robot is in use.

*Quote translated, originally in Swedish

6.2.1 System Configuration

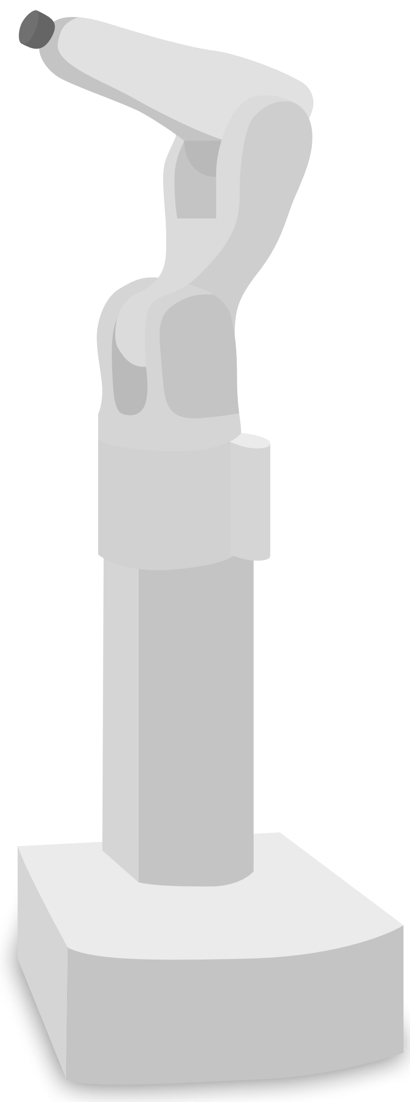
This is Sam

When Sam is asked about his profession, he describes himself as a tech generalist. As a young adult, he decided to study a B.Sc. in automation and mechatronics to gain a broad technical basis, and he has been working in tech ever since graduating. During the past years, Sam has been employed in a tech consultancy firm profiled in the integration and configuration of robot systems. Sam finds working with systems of robots really interesting, especially as robotics and related technologies are evolving extremely fast these days and Sam is constantly challenged to solve new problems and think creatively.

Recently, Sam has been working a lot with a new system of cleaning robots. The system of robots has been developed to support cleaning in the food industry, and owing to the cleaning robots being both collaborative and mobile, this system of robots is paving the way for a new era of industrial cleaning. Sam's role as a system configurator for this system of robots could be described as "the one who makes the system work on site". That is, once a food plant has decided to invest in a system of cleaning robots, the system of cleaning robots must be configured for this unique environment, and that is Sam's job.

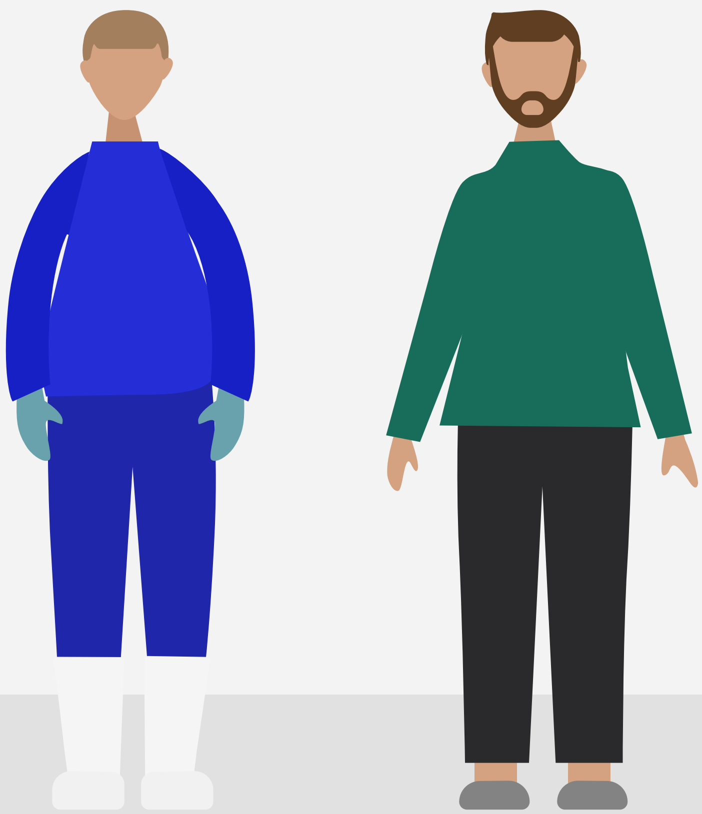
The collaborative aspects, as well as the mobility, introduce a lot of new challenges. Owing to this, the work with implementing this new system of cleaning robots differs a lot from traditional system integration projects. The term system integration is traditionally used to describe projects where robot cells with stationary industrial robots and serving machines are built up. That is, a production environment is built up and adapted for the robot. In contrast, no significant adaption of the environment is required for this new system of cleaning robots. Instead, it is the system of robots that must be configured to be adapted for the existing production environment. The term system configuration is therefore used when describing these kinds of projects.

During the upcoming week, Sam is about to start up the work with the configuration of such a system of cleaning robots in a local charcuterie food plant. Normally, Sam is a part of a bigger team working with system configuration projects. This charcuterie food plant is however quite small, so Sam will take care of the entire system configuration on his own this time.



Configuration preparations

The system configuration project is initiated with a visit to the charcuterie food plant, to ensure he understands the context that the robot system is to be placed in. Sam is therefore on his way to visit the food plant this evening. At the food plant, Sam meets with Nikola who has been working with cleaning in this food plant for many years and he is now the cleaning shift leader. They discuss how the food plant is cleaned today, the number of cleaners working there and how the tasks are divided between them. Additionally, they also discuss how the cleaning procedure differs between different days of the week. In this food plant, an extra thorough cleaning occurs every Friday.



After the discussions, it is time for Sam to actually see the areas that are to be cleaned, so Nikola guides him through the food plant. While walking through the different areas they talk about how the robot system could be integrated here. Sam observes the how the cleaners are working: rinsing off food scraps, applying foam, rinsing off the foam, and so on. Sam notes some challenges that the cleaners seem to face while working. It appears to take a lot of time to rinse off all food scraps from some complex areas in the machines. He also observes how the cleaners have to climb up on some machines to ensure they reach everywhere and bend down all the way to the floor to reach under other machines. These are challenges that Sam will be facing too when configuring the robot system to handle the same tasks.

In addition to the cleaning challenges, Sam also notices a few areas that might be difficult for the robot to pass through. For example, some machines are positioned close to walls or other machines, which makes it difficult to pass by on all sides of the machine even for a human. Also, the floor is tilting slightly where a lot of water flows. During the tour Sam takes pictures and makes notes to capture what he sees, ensuring he will have something to return to while sitting by his computer and working on configuring the system in the virtual model of the food plant.

Sam notes down the order in which the machines are cleaned today, and how the different cleaners work in parallel in the same room. Thereto, Sam notes down a list of preparations that must be carried out before starting the cleaning procedure, what parts need to be removed from the machines, and portable objects in the room that will have to be cleaned manually also in the future. After a long evening observing the cleaning procedure in the food plant, Sam is confident he got all the information needed to begin with the configuration of the robot system and leaves the food plant to return home to his family.

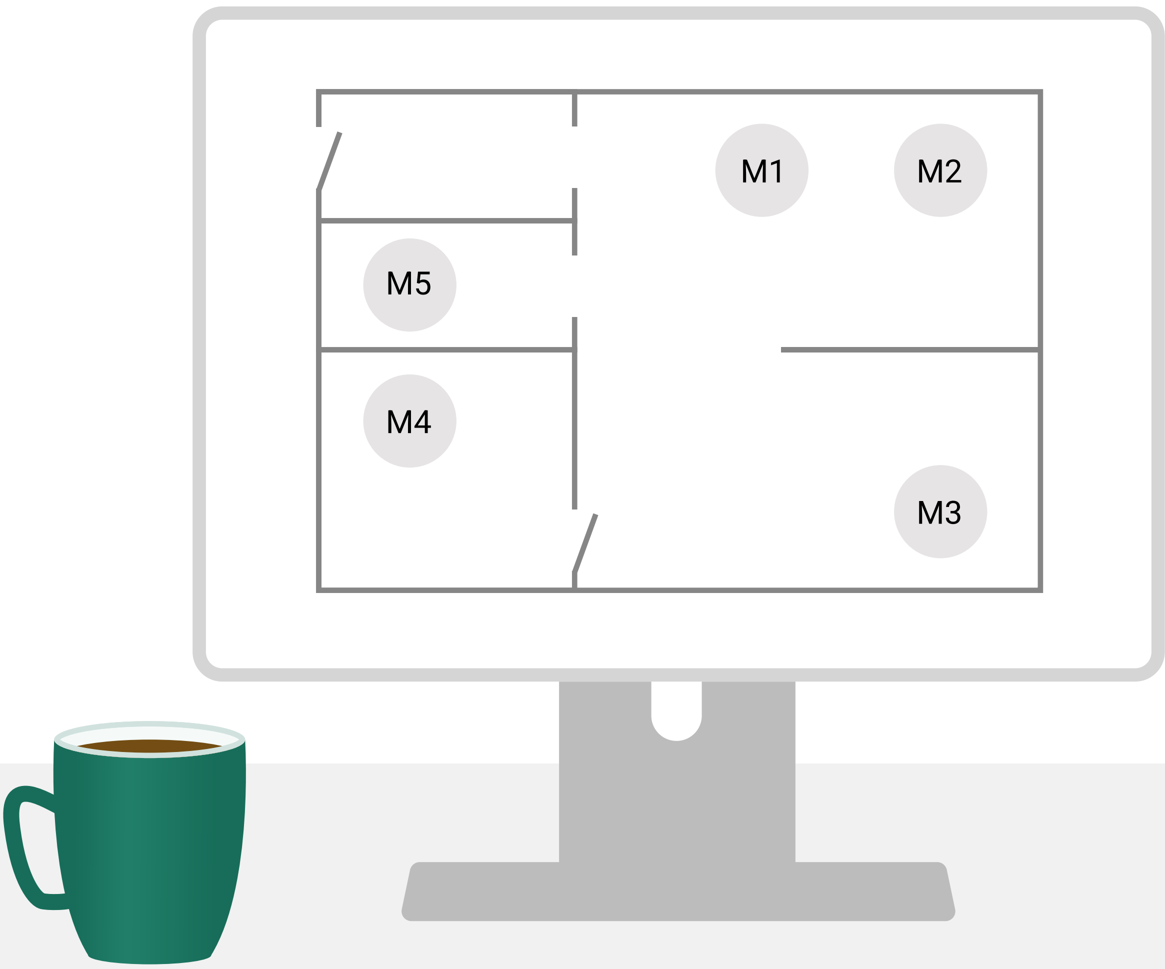
Building a virtual model of the food plant

The following day Sam sleeps a little longer than usual to recover from the late night at the food plant, but once the alarm clock rings it is back to normal. Sam rides his bike to the office to start working on the system configuration. When there, Sam grabs an extra large cup of coffee from the kitchen before sitting down in front of his computer where he opens the RoboClean Configuration Software. This program is used to build and simulate cleaning programs for systems of robots in food plants.

The process of creating a cleaning program can be extensive for large food plants, but roughly it can be summarized accordingly: First, an accurate virtual model of the food plant including all its interiors is built. Based on this virtual model, robot paths for cleaning can be generated for each interior object individually, and these paths can thereafter be connected into a complete cleaning sequence for the food plant. Based on the capabilities and delimitations of cleaning robots, humans must supervise robots and certain cleaning tasks will require human support. A division of tasks between human and robot is made, and this finally results in a first version of a cleaning program for this food plant that can be simulated and evaluated.

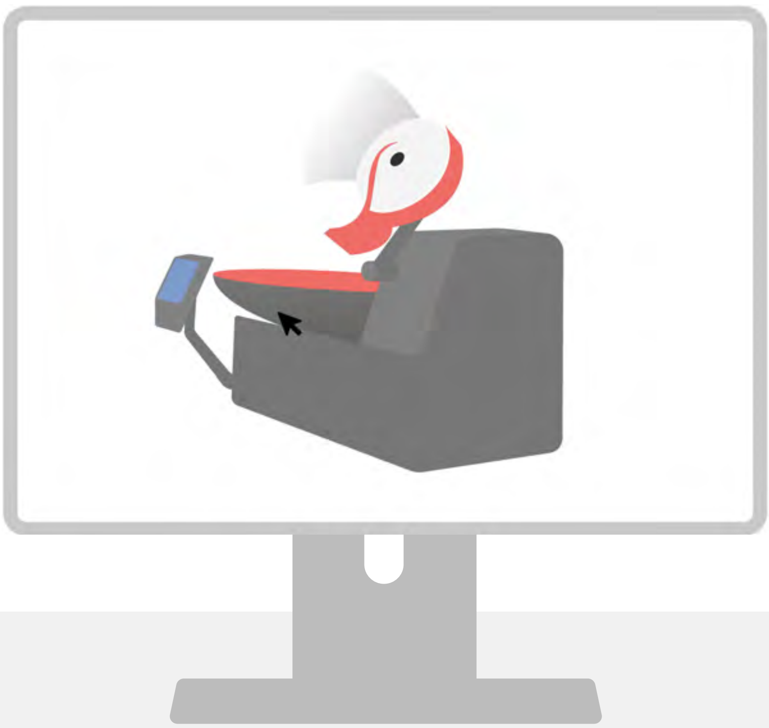
The first step of the system configuration is thus to build a digital model of the food plant. Sam starts with this by uploading a CAD file representing the entire food plant. It is far from certain that CAD files describing food plants exist, rather the opposite. Thanks to the digitalization within the construction industry and improved 3D scanning technologies, it has however become more common that food plants have CAD files describing the facilities in recent years. Otherwise, a new CAD file must be created and this requires a lot of work. When CAD files are missing, Sam or one of his colleagues must visit the food plant and 3D scan the entire facility. With the information gathered from a 3D scanner camera, a point cloud can be created. The points can thereafter be meshed into surfaces to finally create a 3D model of the scanned environment. However, Sam was lucky enough to get a file from the customer in this case. This will speed up the configuration process remarkably.

The CAD file contains a 3D model of the entire food plant layout with walls, floor, drains, pipes for ventilation, and all interior objects like machines and tables. Once the food plant model has been uploaded, Sam begins the work with dividing big surfaces like walls and floors into smaller surfaces. The division is necessary to facilitate robot path generation and make the cleaning process more efficient. When dividing the walls, Sam takes the position of different objects inside the room into account to make sure that the wall sections can be cleaned in conjunction with the machines close to them. Each new surface is also assigned with a so called WML class to ensure it gets cleaned properly. A WML class is a description of how to clean a specific surface, and WML classes are stored in a WML database. To know how to clean a specific surface one must know the hygienic requirements, what material it is made of, what kind of dirt it has been in contact with, and its IP classification. This information is included in the WML classes.



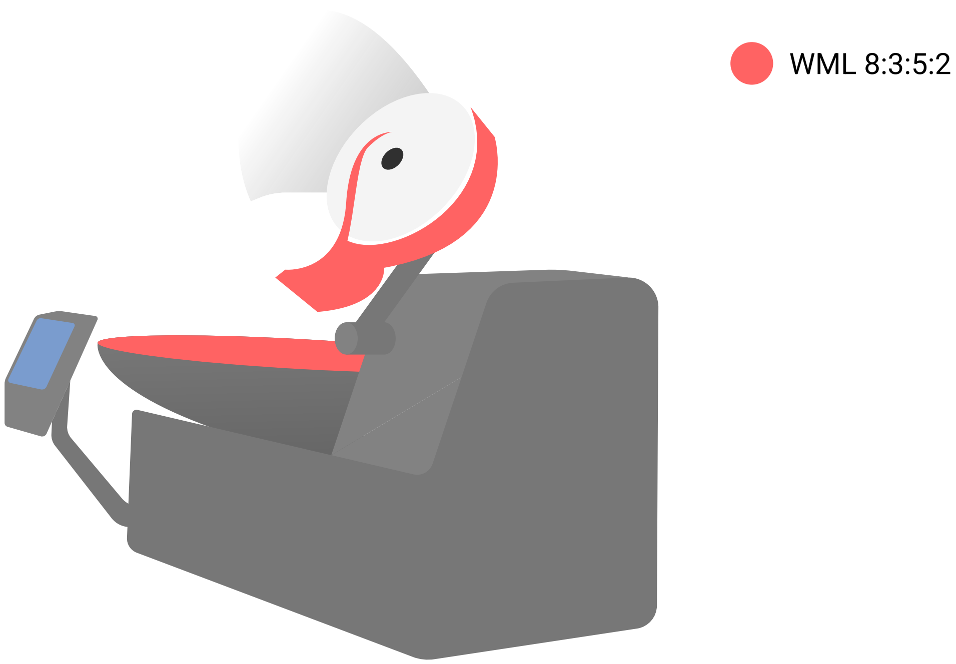
Once the walls and floors have been divided into smaller surfaces, it is time to allocate the machines and other objects inside the food plants and connect these with WML objects. A WML object is a combination of WML classes and a geometrical description. Accordingly, a WML object can be compared to a 3D model describing an object divided into multiple surfaces, where each surface is individually assigned to a WML class. While WML classes are general and can be applied to multiple WML objects, WML objects are specific owing to the geometrical description. For that reason, there is a unique WML object for a meat grinder machine of a certain model from a certain manufacturer, and this WML object can only be used for this kind of machine. Based on the information provided by the WML objects about the object's geometry and how to clean it, an optimized cleaning path can be generated in the RoboClean Configuration Software.

Sam checks what machines are available as predefined WML objects in the WML object library, and is relieved to find that most of the machines in the food plant already exist. Thanks to this, Sam can easily assign a WML object to a machine in the 3D model environment. However, there are not WML objects for every object in the food plant. Most food industry machine manufacturers provide WML object files for their products by now, but it is not always the case. Especially not when it comes to older machines that have stopped being manufactured. The latest version of WML and the collaborative system of cleaning robot has only been out on the market for about a year, and it is a continuous work to update the WML object library with new WML objects. Building new WML objects can be rather time consuming and requires knowledge in cleaning, WML and CAD. At the company where Sam is employed, there is actually a colleague of his specialized in creating these files.



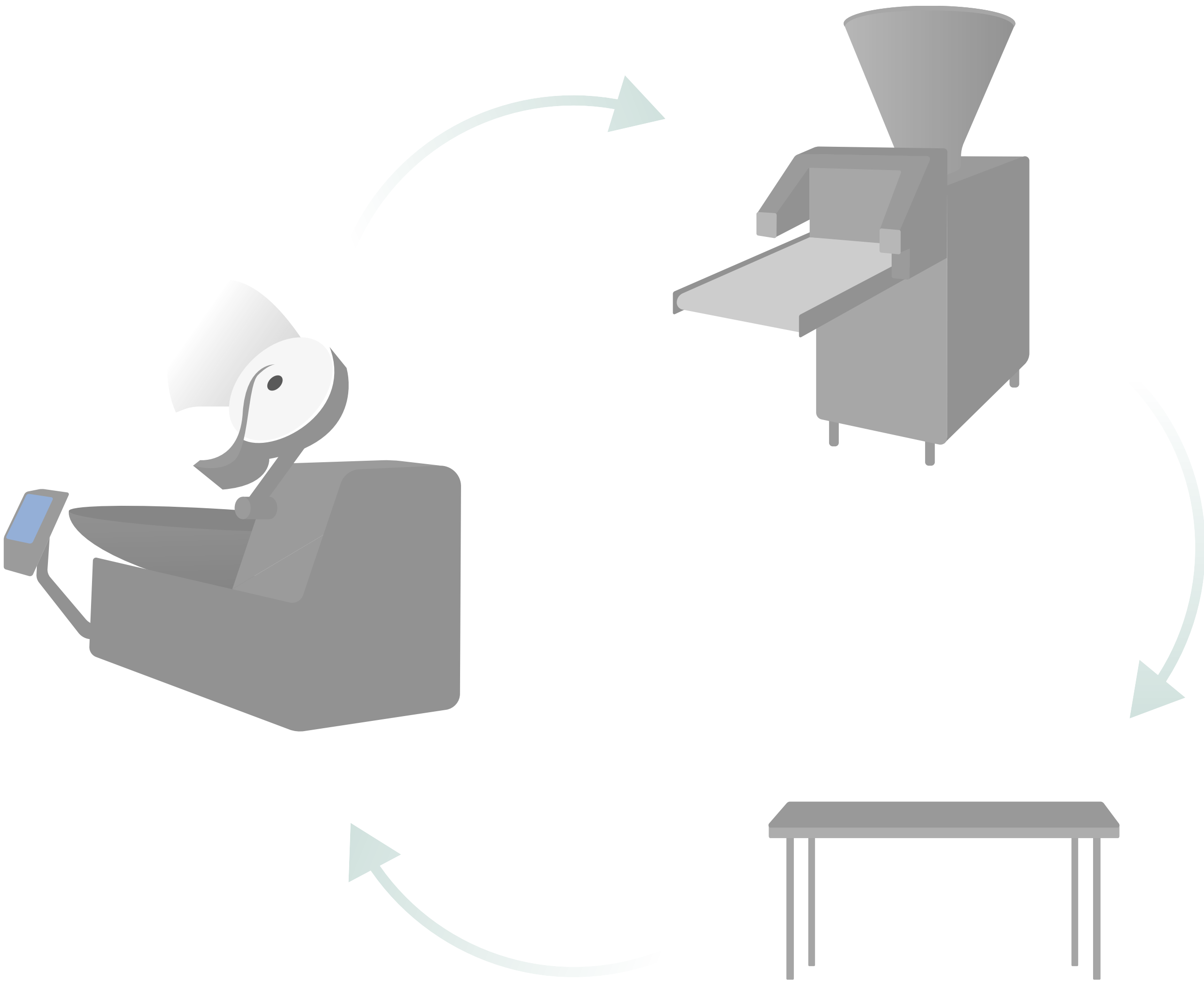
The food plant in this project is rather small and equipped with overall modern machines, and it seems to be only one WML object missing. Therefore, Sam can handle the creation of this new WML object for one of the machines on his own, so he begins with the work of creating one. Sam starts by uploading a CAD file for this machine that luckily could be provided by the manufacturer. Once the CAD file is in place, he continues with connecting the different surfaces of the machine to WML classes in the WML database. The shape of this machine is rather complex, and this requires Sam to make smart decisions on how to divide the surface of the machine into smaller surfaces that can be connected to WML. Further, it is a challenge to handle a number of grooves along the side of the machine, as well as a sensitive electronic area near the display that cannot be exposed to water and chemicals. Sam enjoys building WML objects for things like this machine, as it requires him to think through his decisions and find smart solutions to solve some of the cleaning challenges.

Sam is done with creating the new WML object a few hours later. He assigns the new WML object to the right machine in the 3D environment, and he also makes sure to upload this new WML object to the WML library. All objects inside the food plant model have now finally been assigned with a WML object, and it is starting to get late. Sam takes a look at the model one last time for today. Happy with the result, Sam packs up his things to return home to his family. While pedaling home on his road bike, he concludes that the configuration has worked out smoothly so far. Building the virtual environment is a procedure that usually can take a lot of time, but on a project like this when all CAD files are available and up to date, and WML objects for most of the machines already exist, the procedure is much quicker. Sam is very content with getting this far with the configuration in just one day.



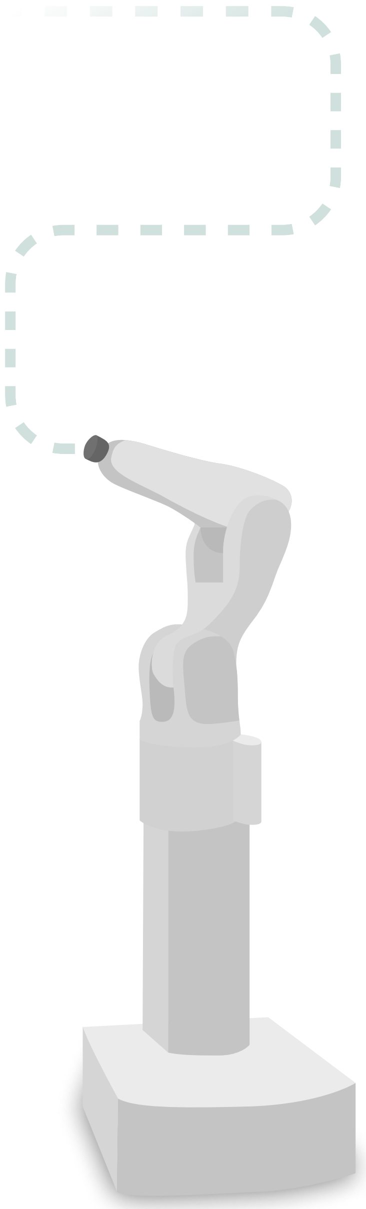
Setting the cleaning sequence

Back at work the next day, Sam grabs his usual big cup of coffee from the kitchen and brings it to his desk where he opens up the RoboClean Configuration Software again. The next step in the system configuration process is to establish a cleaning sequence, that is the order in which the robot will clean the objects inside the food plant. Based on his understanding of the food plant and how it is cleaned today, Sam selects the machine in the food plant where he believes it would be best to begin the cleaning sequence. Starting at the machine Sam selected, the software thereafter suggests an order for the robot to clean the different objects based on their mutual placement inside the food plant and distance from each other. Sam finds the suggested order to fit the environment and accepts it.



Generate robot paths for cleaning, object by object

The following step is to generate robot paths for cleaning. In other words, this step is about defining the robot's movements while cleaning and setting parameters for how the robot will go about cleaning an object. The path generation is done for each object individually, so one could almost describe the result of this stage as multiple, disconnected short robot cleaning programs.



First, he must however make sure to add all cleaning parameters that are specific for this food plant. Cleaning parameters specific for a food plant cover aspects like what range of water temperature is available, what water pressure they have access to, what type of food is produced there, what cleanliness classification do they follow and what kind of chemicals they use for cleaning and disinfection. Sam returns to the information gathered during his visit to the food plant and types in these values in the RoboClean Configuration Software.

Once the factory specific parameters have been set, it is time to start planning the robot path for the objects inside the food plant individually. Sam takes on one WML object at a time, starting with a meat grinding machine. The RoboClean software collects all essential parameters for the path generation automatically based on the geometry, the WML classes connected to the object, the factory specific input, from what direction the robot is coming, and also the abilities and restrictions of the cleaning robots. Hence, all Sam has to do is to review, modify or accept these parameters, and wait for the software to generate an optimized robot cleaning path for the object.

Simulate robot paths for cleaning, object by object

To review a path once it has been generated, Sam simulates how a robot would clean following this path. His aim is to optimize the path with regard to efficiency and sustainability. Factors like cleanliness, resources used, time, wear on the robot, and collaboration with humans should be taken into account when analyzing these paths.

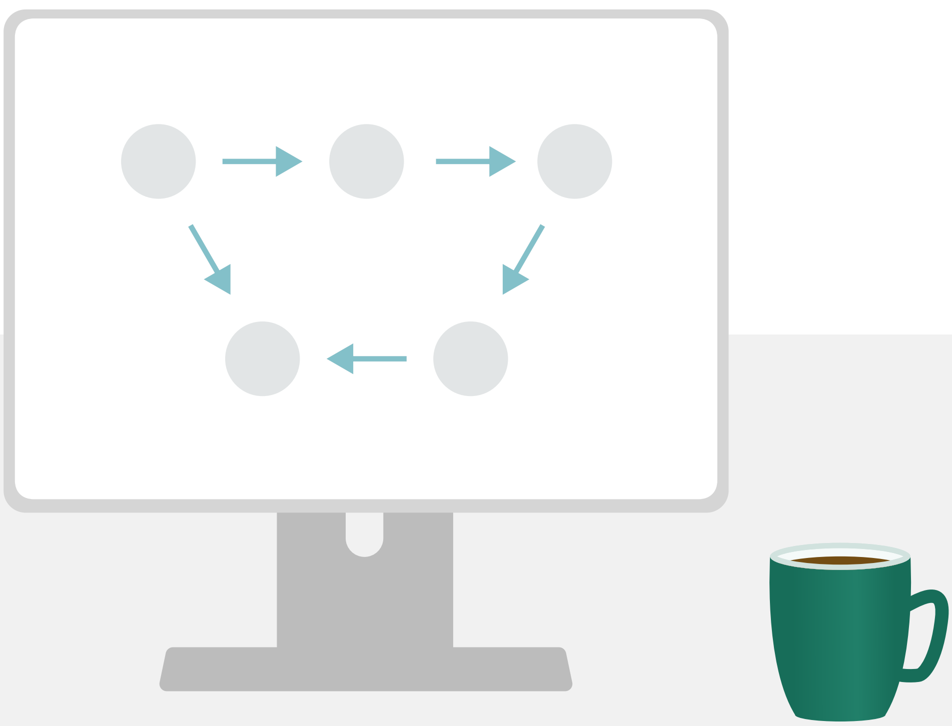
Sam is notified by software that there is a corner inside the machine that the robot path does not cover. He studies the path and concludes that the best option here is to keep the path as it is, and instead have a cleaner to clean this area. Sam also looks into results on overall coverage when spraying water, and notes two surfaces are marked as possibly not covered well enough. From previous experience and the observations from the food plant, Sam recognizes that these surfaces on the machine are difficult to clean due to the grooves along the sides. Therefore, he makes some adjustments in the path to ensure the coverage is at a sufficient level. After a final investigation of the path, Sam is happy about the results and moves on to the next machine where the same procedure follows, generate the path, review the simulation of the path, and make changes to the path if needed.

Generate a cleaning program

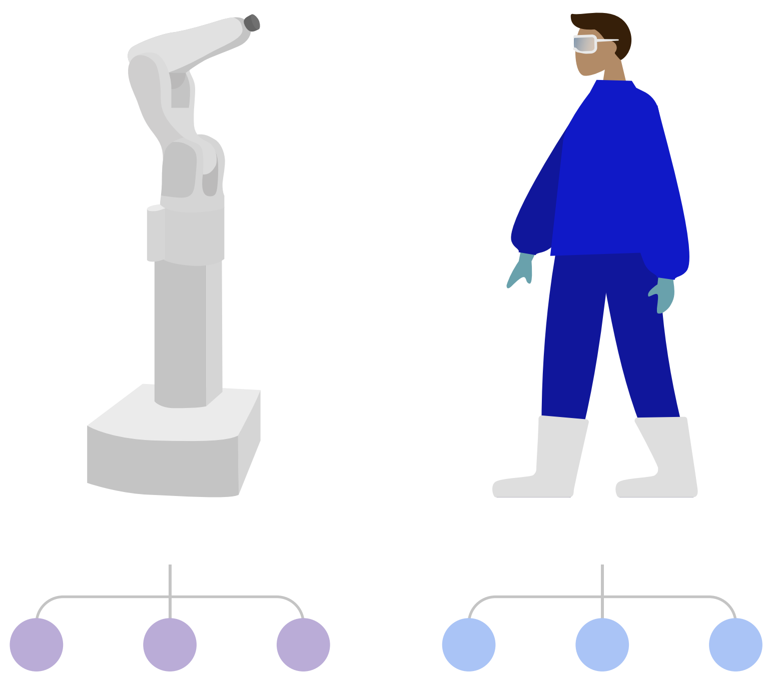
Once the robot paths have been generated for all individual objects and areas in the food plant, it is time to connect the pieces and put together a complete cleaning program. Based on the order defined in the cleaning sequence, the RoboClean Configuration Software connects the robot paths for cleaning individual objects with additional robot paths defining the movement of the robot between the different objects. The result is one long chain of robot paths that defines the robot's movements through the food plant during an entire cleaning program.

Sam reviews the resulting chain of robot paths and notices that it takes the robot through an area where the floor tilts slightly. During his visit to the food plant, Sam noted that lots of food scraps tend to gather there, and in addition, it flows a lot of water in this area. From experience, he knows that the combination of the tilted floor, food scraps, and the water might make it difficult for the robot to pass there. Therefore Sam modifies the robot’s path to a little longer, but likely smoother alternative route.

When Sam feels satisfied with the way the robot will move, it is time to work on the cleaning sequence for the human cleaner. Based on the robot cleaning paths and the results from the analysis of his simulations, the RoboClean Configuration Software has identified all areas where the robot cannot clean sufficiently well. Further, while reviewing the robot path simulations for each object, Sam also manually marked all areas where he figured it could be difficult for the robot to clean due to the position or shape of the area. Based on this, the software has now generated a list of all areas where the cleaner needs to assist the robot.



The tasks carried out by a human cleaner are also involved in a complete cleaning program, so Sam makes up a plan for how to handle the cleaner's tasks, involving the areas where the robot cannot complete the cleaning on its own as well as other tasks that need to be handled by the cleaner, such as the preparations of the room and cleaning of loose objects. When defining the order in which a human cleaner would go about cleaning a room, the work by the robot in parallel must be taken into consideration. They cannot be cleaning the same machine at the same time as they would likely just be in the way for each other, and the cleaner should neither be positioned too close to the zone where the robot sprays media to avoid getting splashed. With these parameters taken into consideration, the RoboClean Configuration Software generates a suggested cleaning sequence for the cleaner and Sam reviews the result. The suggested cleaning sequence for the cleaner looks good, so Sam confirms this and compiles the division of work by human and robot into a complete cleaning program.



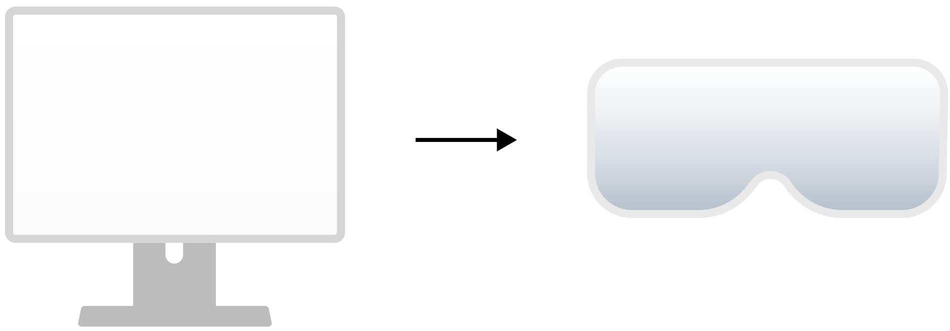
Simulating the cleaning program

After compiling the first version of the cleaning program, Sam makes a simulation of the complete cleaning of a food plant. During the entire system configuration process, Sam has continuously made simulations of the different parts of the cleaning program individually, but now he wants to make sure that the cleaning program works smoothly and efficiently in its entirety. Sam analyzes the program carefully to ensure everything works as planned, and he also reviews all measurable results like usage of power and media, time, and workload on humans. It is also of importance to study the result of the division of work between human and robot, to make sure that no part is delayed by the other nor that no part remains unoccupied for too long. Based on the result, Sam makes some minor adjustments to the program before he declares the cleaning program as ready for testing.

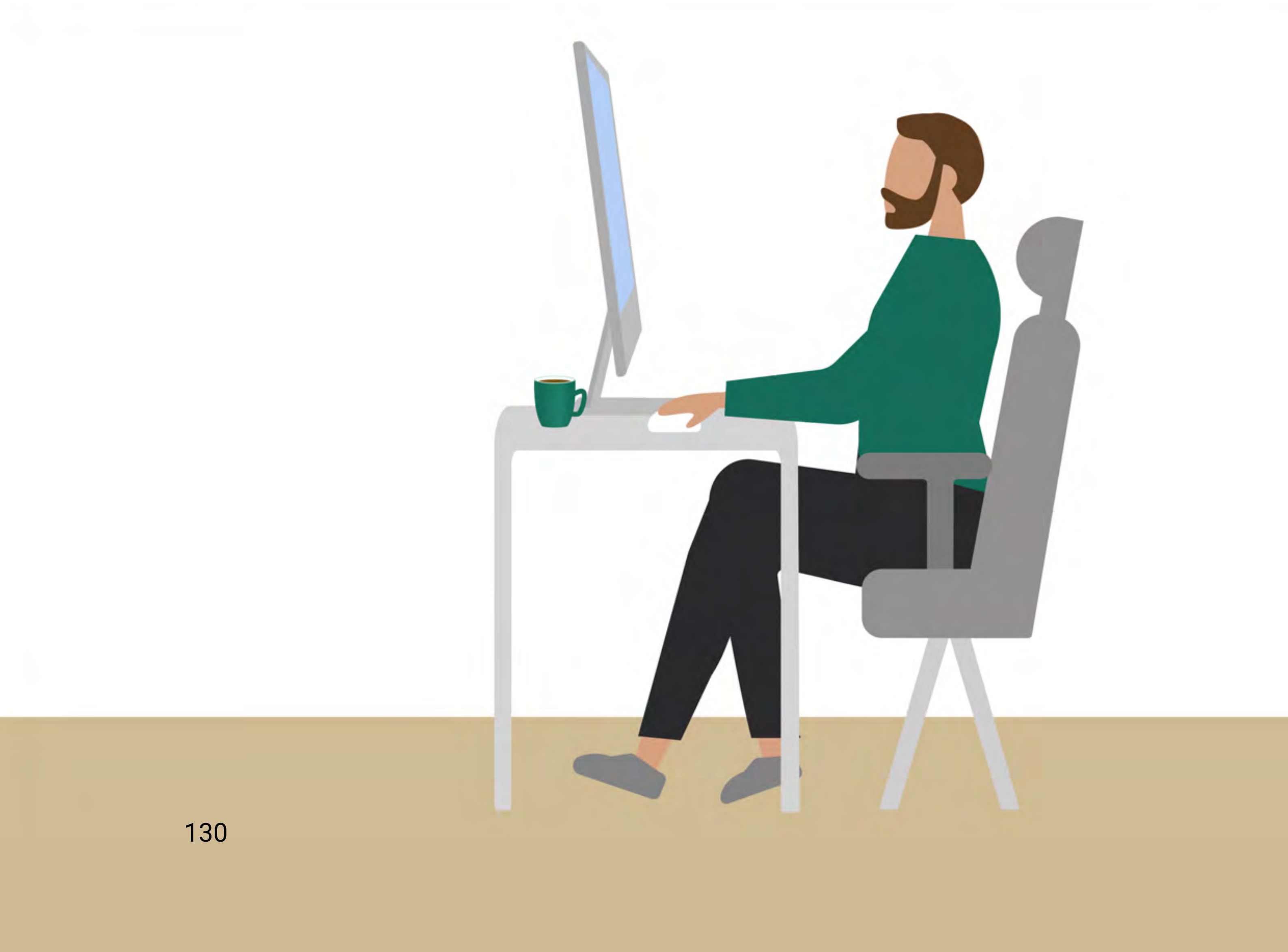
Define instructions for the cleaner

When an efficient cleaning program that works well for both the cleaner and the robot is finalized, Sam begins the work of defining cleaning instructions for the system operator. The instructions describe what the system operator should do when and where, according to the cleaning sequence, and the system operator will receive these instructions while cleaning.

In the RoboClean configuration software, Sam defines what instructions the system operator will need and at what time he or she will need them. This includes what objects inside the food plant the system operator should clean, which surfaces on these objects are likely still dirty after the robot has done its part of the work, and how these surfaces should be cleaned. The instructions for how to clean and what cleaning parameters to make use of are based on the WML classes connected to the surfaces. Thereto, Sam adds the confirmations needed between the cleaner and the robot to ensure the robot waits for approval before moving on to the next step, ensuring the cleaner has done its part of the cleaning in this step. This is an important procedure to follow to ensure that the cleaner and the robot are in the same phase of cleaning all the time.



Sam has now completed the configuration of the first version of a cleaning program in the RoboClean Configuration Software. However, he is not completely done yet. During the factory visit, Sam found out that a more thorough cleaning program that can be run once a week is needed in addition to this cleaning program for everyday use he just built. Luckily, Sam can reuse many parts from the first cleaning program when building the second. To make this cleaning program more thorough, Sam adjusts some of the cleaning parameters, and the hygienic requirement on the walls and floor is increased. Further, Sam adds an extra step at the end of the cleaning procedure with instructions on how to decalcify the machines. After finalizing the two cleaning programs Sam wraps up and leaves work for the day, excited to return to the food plant to test his result in reality soon.

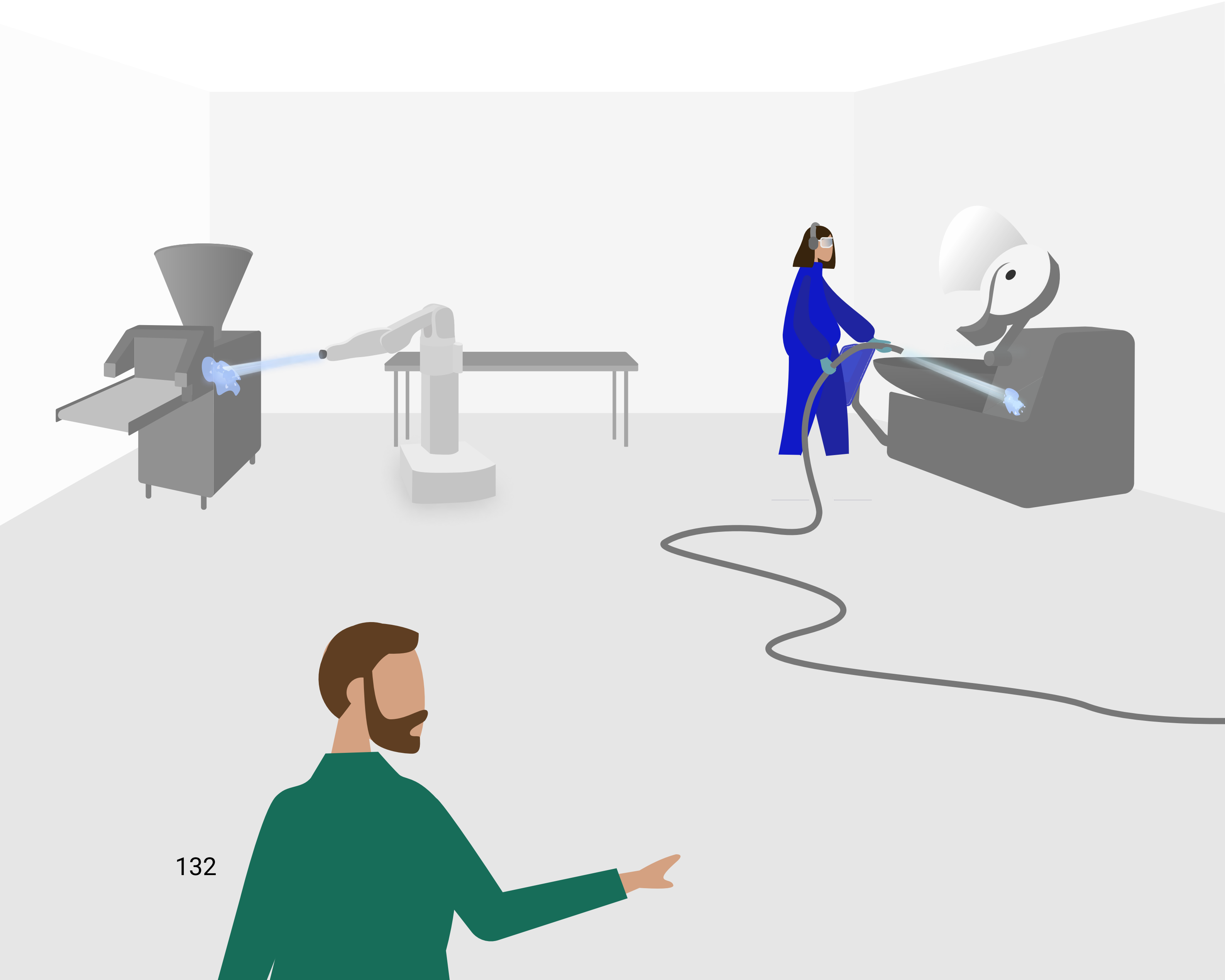


Testing cleaning programs on site

A few days later, Sam returns to the food plant to test the program that he has built for the RoboClean system in reality. Simulations in a virtual model of an existing environment are a powerful tool. Nevertheless, the match between reality and its virtual model is never 100\%. The circumstances in the simulations are precise and constant, while in reality there is always a level of uncertainty as the world is ever changing. Consequently, Sam needs to test the program to ensure it works well also in reality.

The first step is to ensure that the robot program works as planned. The robot runs in the path planned, but without spraying water or chemicals. During this first step, Sam ensures the robot can move according to the planned paths and that nothing is in its way. Thanks to the well prepared 3D models of the food plant, everything works as planned and Sam moves on to running the cleaning program with water and chemicals. Sam observes the robot working in all the different steps of the cleaning procedure to identify any issues the robot has with following the program, covering all areas, or successfully completing a task. He carefully documents all issues identified and goes back to the RoboClean Configuration Software to handle the problems and make an updated version of the cleaning program. Once he has generated a new version of the cleaning program, Sam runs it again and the procedure repeats itself once more. This time, Sam is lucky and only has to make a few small changes to the robot's path. The program is run again with only the robot, and now everything seems to be working as planned.

Once the program has been tested with only the robot and all necessary updates have been made, it is time to test-run the entire cleaning process with a cleaner. This is to ensure that the task division works efficiently and that the food plant gets clean enough. A cleaner called Emelie carries out the cleaning in collaboration with the robot. The test indicates that Sam's estimations of the amount of time a clea-ner needs to do a certain task are a bit off. The estimated time is not enough for certain tasks, while for other tasks it seems to be too much. Hence, Sam makes a few changes to the cleaning sequence to ensure an efficient cleaning process. After a few iterations, Sam and Emelie are satisfied with the results and Sam leaves the food plant with its new system of cleaning robots ready to use.

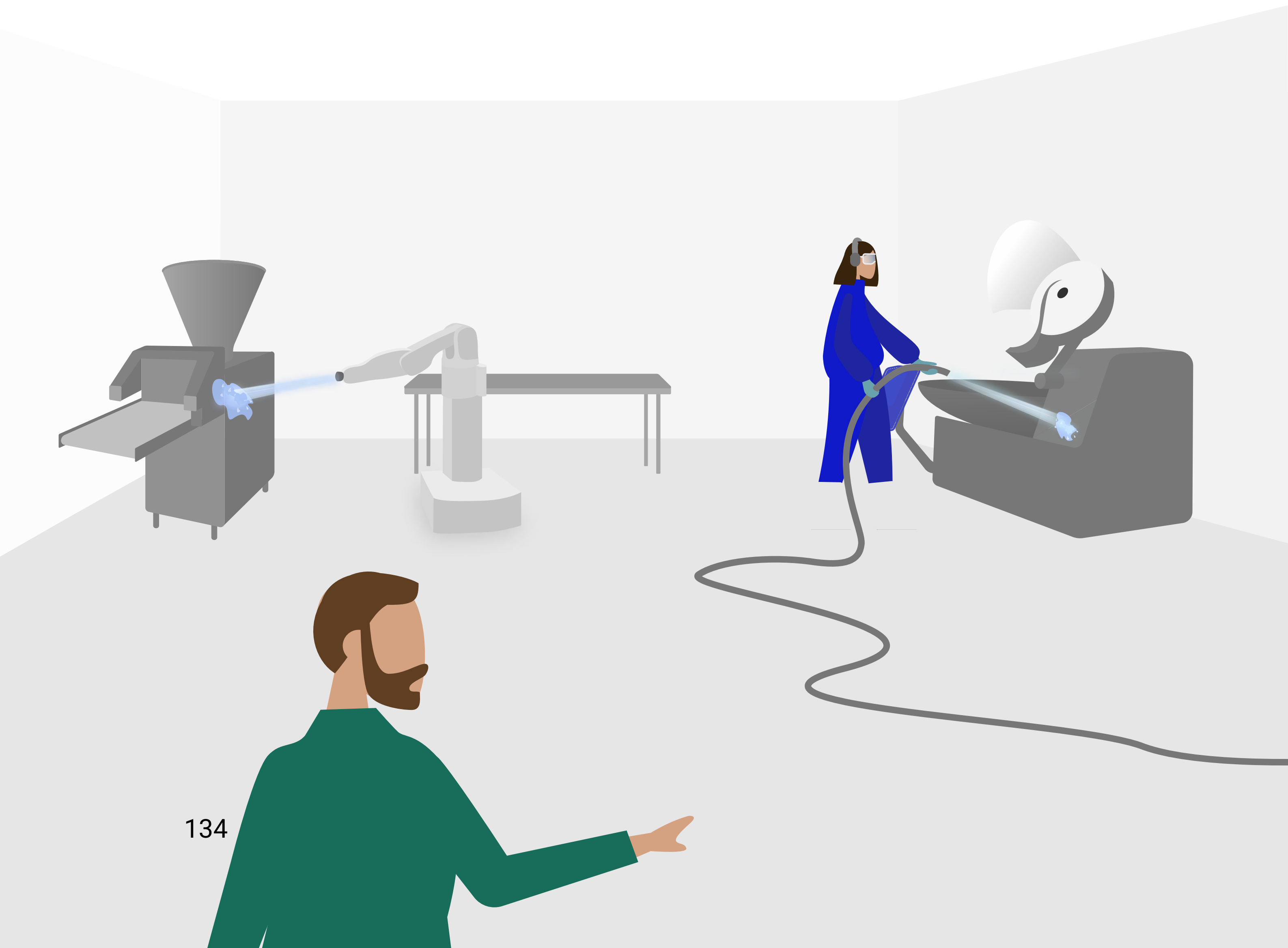


Adjustments to the cleaning program after some time has passed

A few weeks later, Sam gets a call from Nikola, the person responsible for the cleaning in the food plant whom he met a few weeks ago. He describes how the system of cleaning robots already has shortened the cleaning time and improved the cleanliness result in the food plant. There are however some aspects in need of adjustments. The cleaners have noticed a few areas where the robot always leaves some dirt, but this area is not marked as one of the zones where the cleaners must support the robot. As the system seems to be unaware of this, the result is that the cleaners must try to remember to always clean these spots after the robot themselves. Thereto, there is one point in the process when the robot and cleaner are out of sync, resulting in the cleaner becoming forced to wait for the robot before moving on with his work.

Sam returns to the food plant to see the problems himself before making the changes in the RoboClean software. Sam observes Emelie cleaning the room in collaboration with the robot. He sees the problems that were described to him and try to come up with solutions to the problem. The areas that never seem to get clean enough are a simple task and something that Sam is used to handling. The task division is a complex task to solve, and while watching the process today he tries to come up with a better solution.

With a few ideas of how to solve the problems in mind, Sam returns to the office and his computer to try out the alternatives in the RoboClean Configuration Software. First, Sam takes care of the areas that are not clean enough. He change the robot path for those objects to ensure those areas are rinsed off more thoroughly. From Sam's experience that is usually enough, so he moves on to the next problem. Looking into what Sam saw during the visit to the food plant he changes the order for a few tasks to match the time needed for the cleaner and the robot for the different tasks. Sam is happy about the results and returns to the food plant to make the same changes in production. He stays to watch the next cleaning shift, to ensure the changes are sufficient. Sam follows the smooth cleaning procedure, and afterward, Emelie ensures Sam that she is happy about the results too.



6.2.2 System Operation

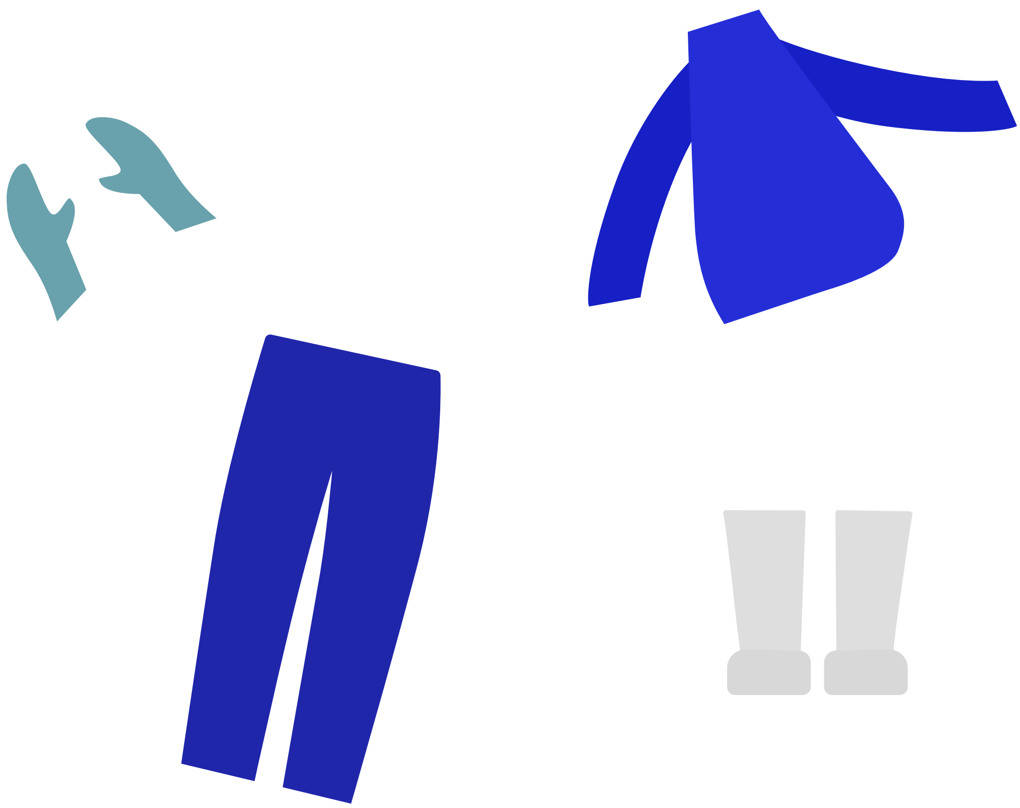
This is Salam

Salam has been working as a cleaner in a food plant for two years. He is employed by an industrial cleaning firm and has been cleaning in a charcuterie food plant since the start of his employment. When Salam first heard from a friend about a job opportunity in industrial cleaning, he was hesitant. The work is done during the night, the work environment is unpleasant and the work tasks are heavy. Working as a food industry cleaner is no one's dream job. But it is a decent job, and Salam really needed a job at that time. So, ultimately he decided to give it a try, and today he is glad he did so.

One of the things Salam likes about his job is the fact that you can see the results of your work clearly. You begin the shift in a dirty room and you leave it spotless, and that transformation is incredibly satisfying. However, the best thing about his work is probably the freedom. As long as he gets the job done in time, he can handle his own business at work without controlling managers hanging around his neck. It might not be a high status profession, but it is a good job with a decent salary, and thanks to the cleaning company's investments in a cleaning robot system the work conditions have also improved a lot recently.

Getting ready for work

Time is 22.40 when Salam parks his car outside the charcuterie food plant. He enters the factory and walks over to the changing room. Most of his cleaning colleagues are already there, and Salam changes into workwear during some small talk. First, he puts on a white coat, trousers, and a hat. If the beard grows longer than 3 mm, wearing beard protection is also required. Salam tries to shave daily to avoid the disturbing plastic net that is worn over the chin. Thereafter, he puts on an additional layer of clothes that is specific for the cleaners. These pieces of clothing are made from a blue, water-resistant fabric that looks like it is PVC-coated. Finally, he also puts on a pair of white rubber boots, rubber gloves, and hearing protectors.



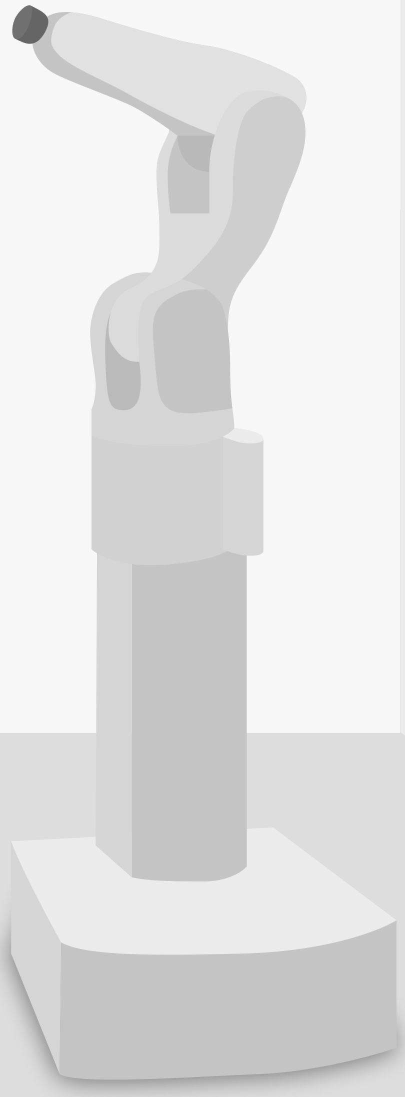
After the change of clothes, Salam heads toward the washing area that separates the food production from the rest of the factory. He washes his hands thoroughly and applies disinfectant. Once this step is done, he is ready to enter the food production area.

The Cleaning Robot

The first thing Salam does once the work shift has started is to walk over to the room where the robot cleaner is located. It is a collaborative and mobile cleaning robot, and functions as a cleaning assistant. The robot takes care of most of the monotonous cleaning work while Salam manages the more challenging and complex tasks.

When the food plant first announced that they would invest in a system of cleaning robots, Sam was very skeptical. Nearly scared. What would this technical upgrade result in? What if robots would take over their jobs? However, it turned out that his fears were all in vain.

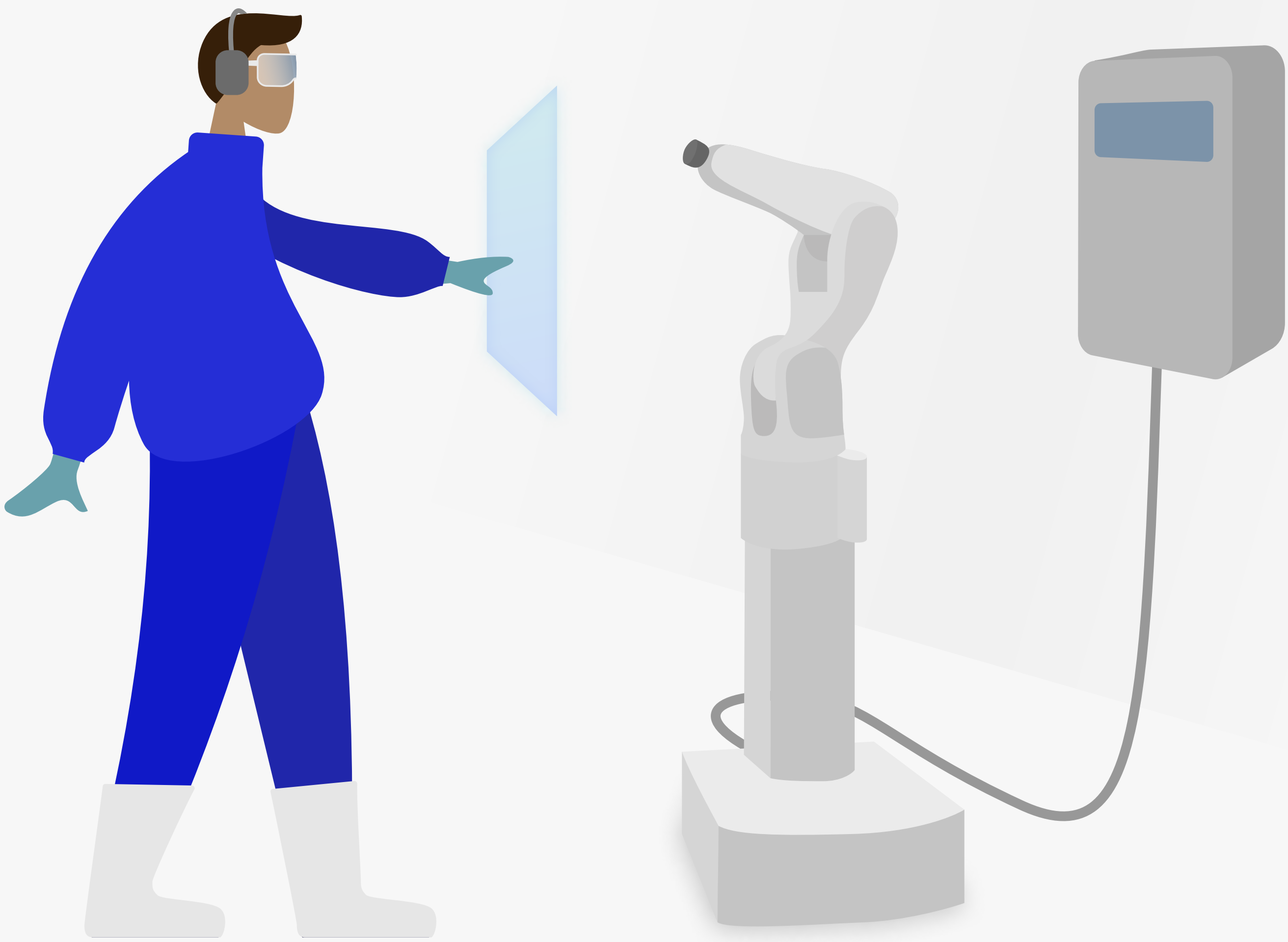
After they implemented the system of cleaning robots in the food plant half a year ago, Salam feels like his work has not only become less tiring, but also more respectable. Supervising cleaning robots using the latest technology doesn't sound too bad. Anyways, the change introduced by the system of cleaning robots was much needed and for the better, and it is clear that it has made the cleaning procedure more efficient. A pair of augumented reality (AR) safety glasses are placed in a charging station next to the robot. These are used as the primary medium for Human-Robot Interaction, HRI.



Salam picks them and activates them by pressing a button located on the side of the frame. With the glasses activated, Salam expands the AR screen in his glasses using hand gestures.

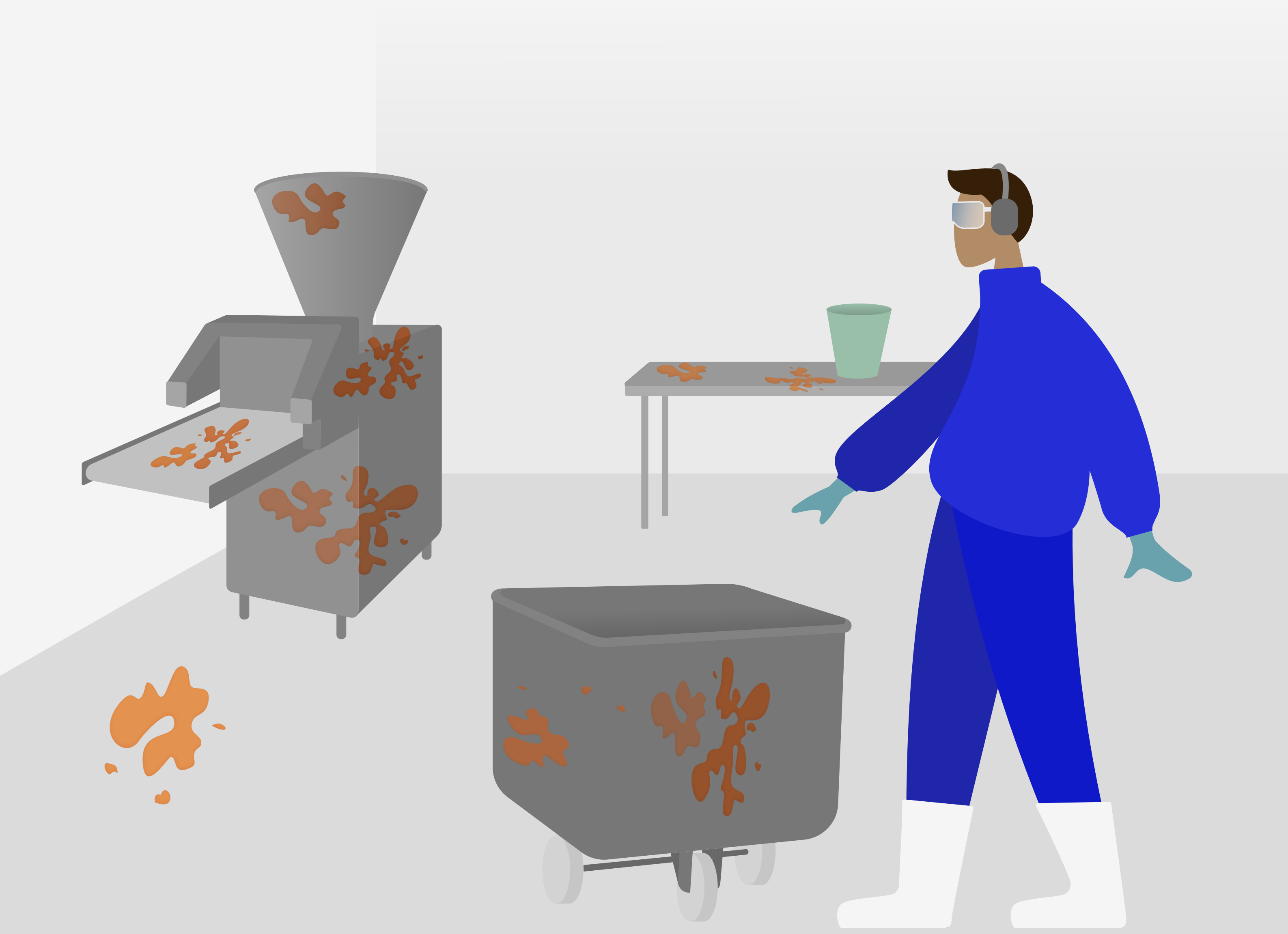
An interactive AR screen becomes visible in front of him and gives him the instructions to drive the robot over to the pump station located inside the production hall.

Salam drives the robot over to the pump station. In accordance with the instructions Salam receives through his smart safety glasses, he connects the robot to a hose that provides it with power, water, and chemicals. Then, he selects what cleaning program to use by interacting with the menu available on the AR screen in front of him.



Preparations

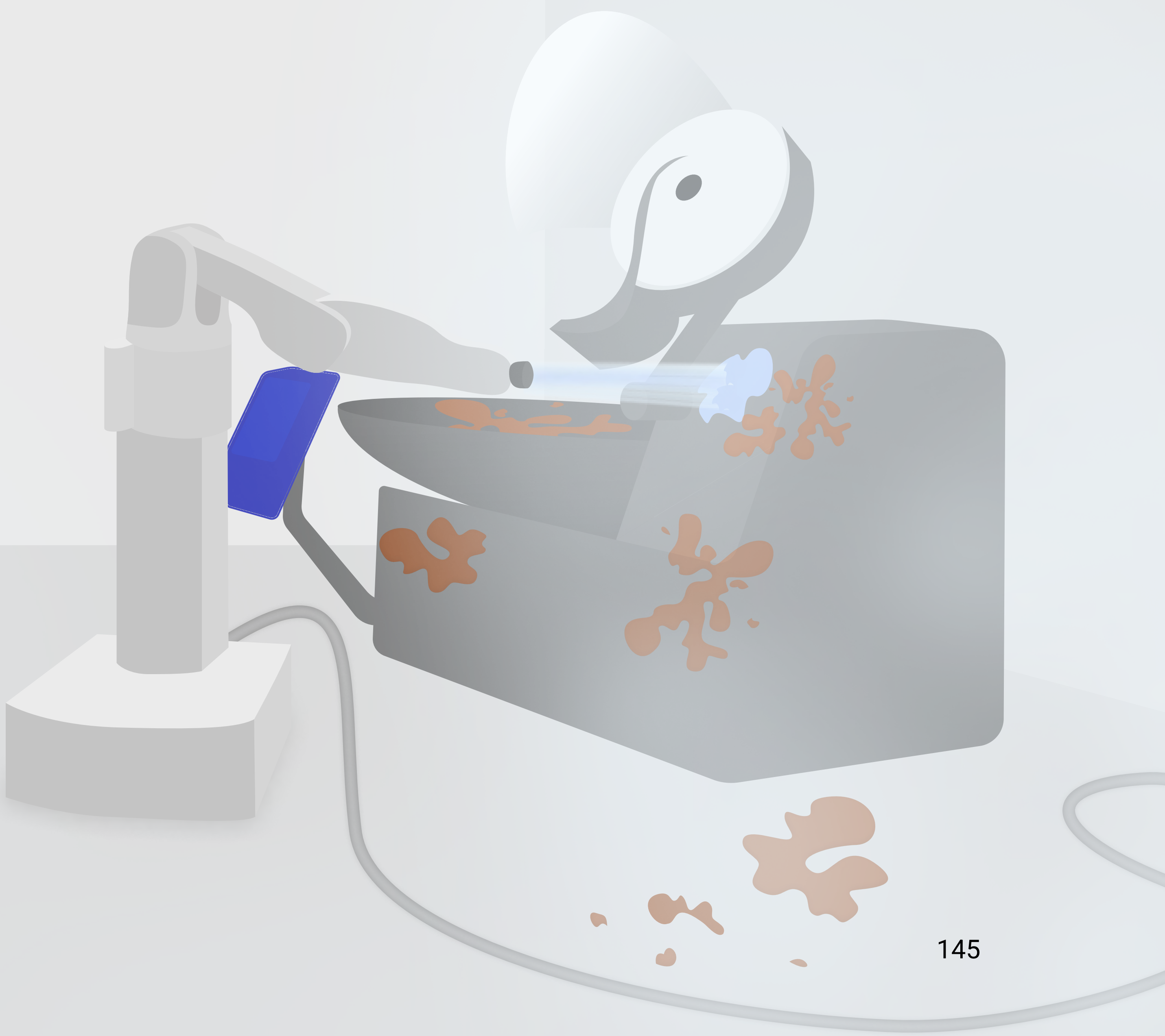
Next, Salam receives instructions on how to prepare the production hall for cleaning. A virtual model of the production hall was used when configuring the system of cleaning robots, and to avoid issues while cleaning it is important to make sure that the physical reality matches the virtual model. Therefore, all loose objects like trolleys and buckets should be moved to another room where Salam can clean them manually. The same goes for a few smaller parts of the machines that need to be removed and cleaned separately. Some of the machines should also be put into a cleaning mode, meaning that the machines are running at reduced speed.



Further, some of the machines have sensitive control panels and other electrical parts that must be covered with plastic to avoid water damage. The smart safety glasses help Salam to keep track of all the preparations and make sure they are executed properly. Once all preparations are done, Salam uses the AR menu in his glasses to confirm that the production hall is prepared and that it is now time to begin with coarse rinsing.

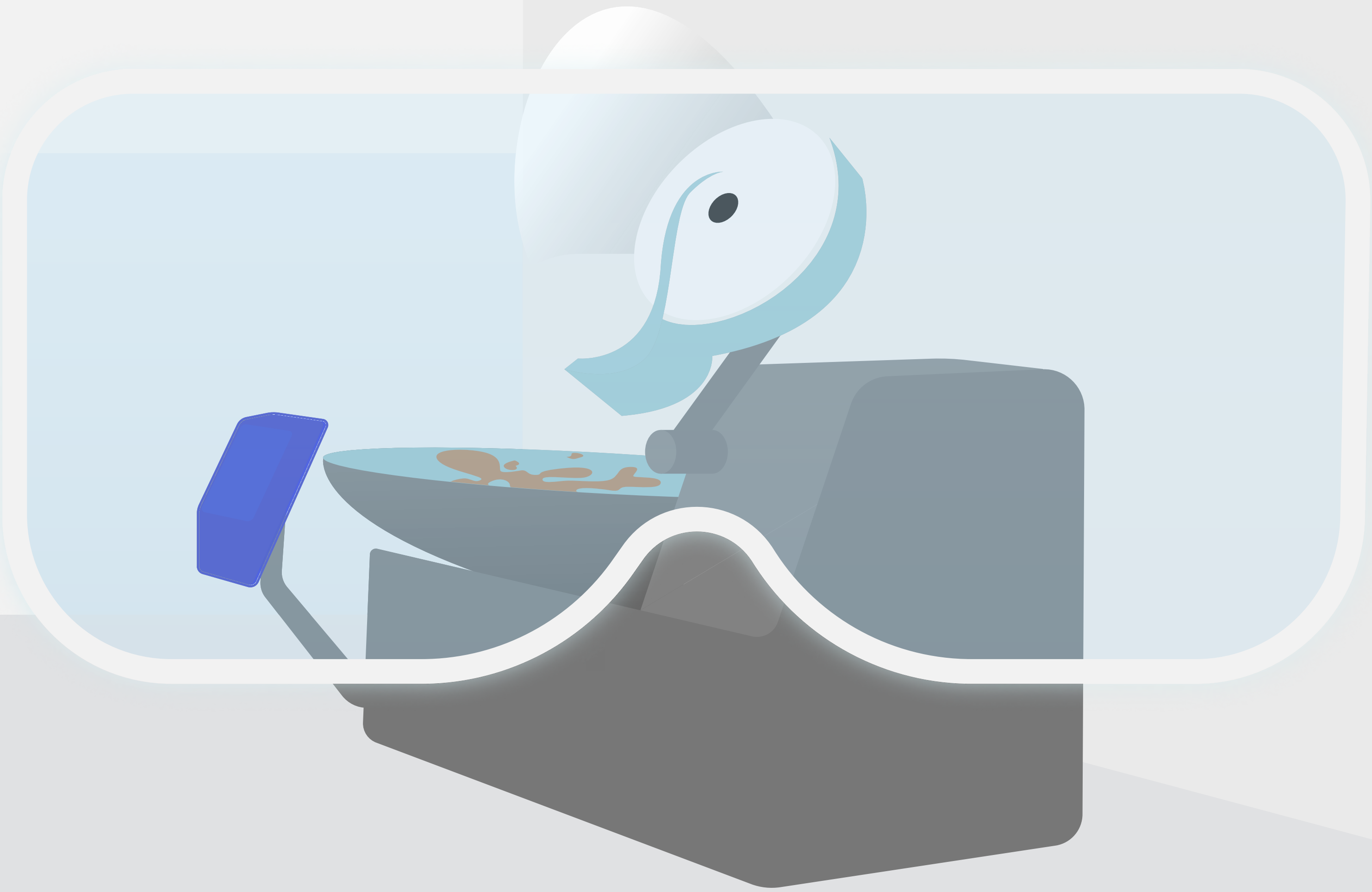
Coarse Rinsing

Since implementing the cleaning robot system the cleaning process has become quicker, nevertheless, coarse rinsing remains the most time consuming part of the cleaning procedure. The purpose of this step is to rinse off the entire room with pressured water to remove all dirt that is visible to a human eye. Thus, the robot begins to spray water on one of the machines, a meat grinder. The robot works autonomously following a preset program set up during system configuration. However, the robot cannot rinse off the entire room on its own, and collaboration with a human cleaner is therefore necessary. This is because some areas inside the production hall are located out of the robot's range, and also some of the more complex cleaning tasks require human flexibility and problem solving skills. Thereto the robot arm will have a nozzle attached to it and it will need assistance for more simple tasks too, such as opening and closing machines.



Once the cleaning program is running, the smart safety glasses provide Salam with suggestions on what he can start doing to optimize the procedure. Salam walks over to the room next door, in accordance with the instructions given, to take care of the trolleys and buckets he moved there previously. While working, Salam also gets updates about the progress of the robot. These updates give him control over the situation and a good overlook of how the work is proceeding. Salam finishes rinsing off the trolleys and buckets and enters back into the room where the robot is working.

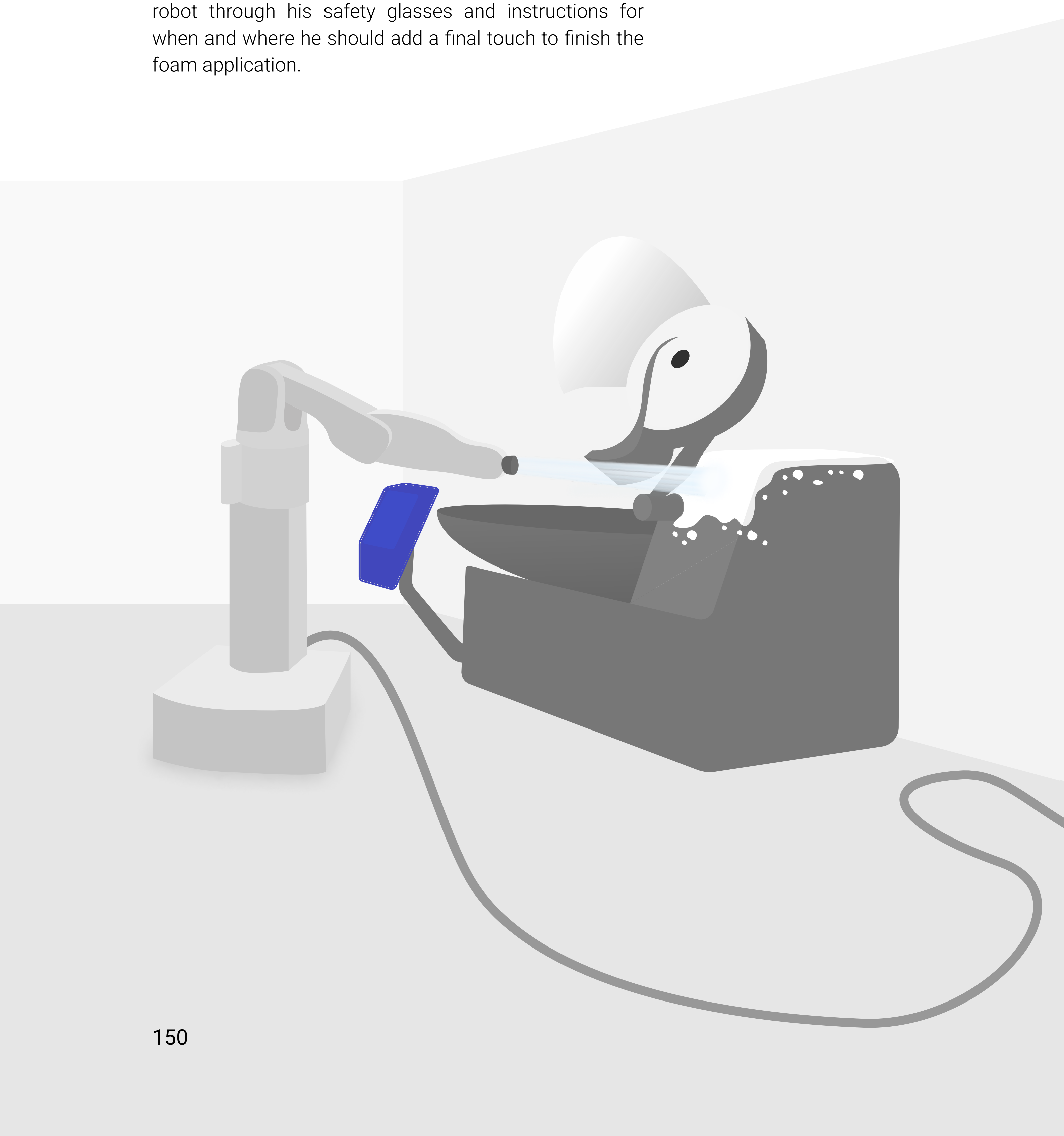
The robot has finished rinsing off the meat grinding machine, and is currently working on a machine for sausage production on the other side of the room. Salam walks over to the meat grinding machine and uses his smart safety glasses to check what is left to do here. With the use of AR, all areas that the robot hasn't been able to rinse off sufficiently are marked, thereby Salam can quickly identify the remaining food scraps.



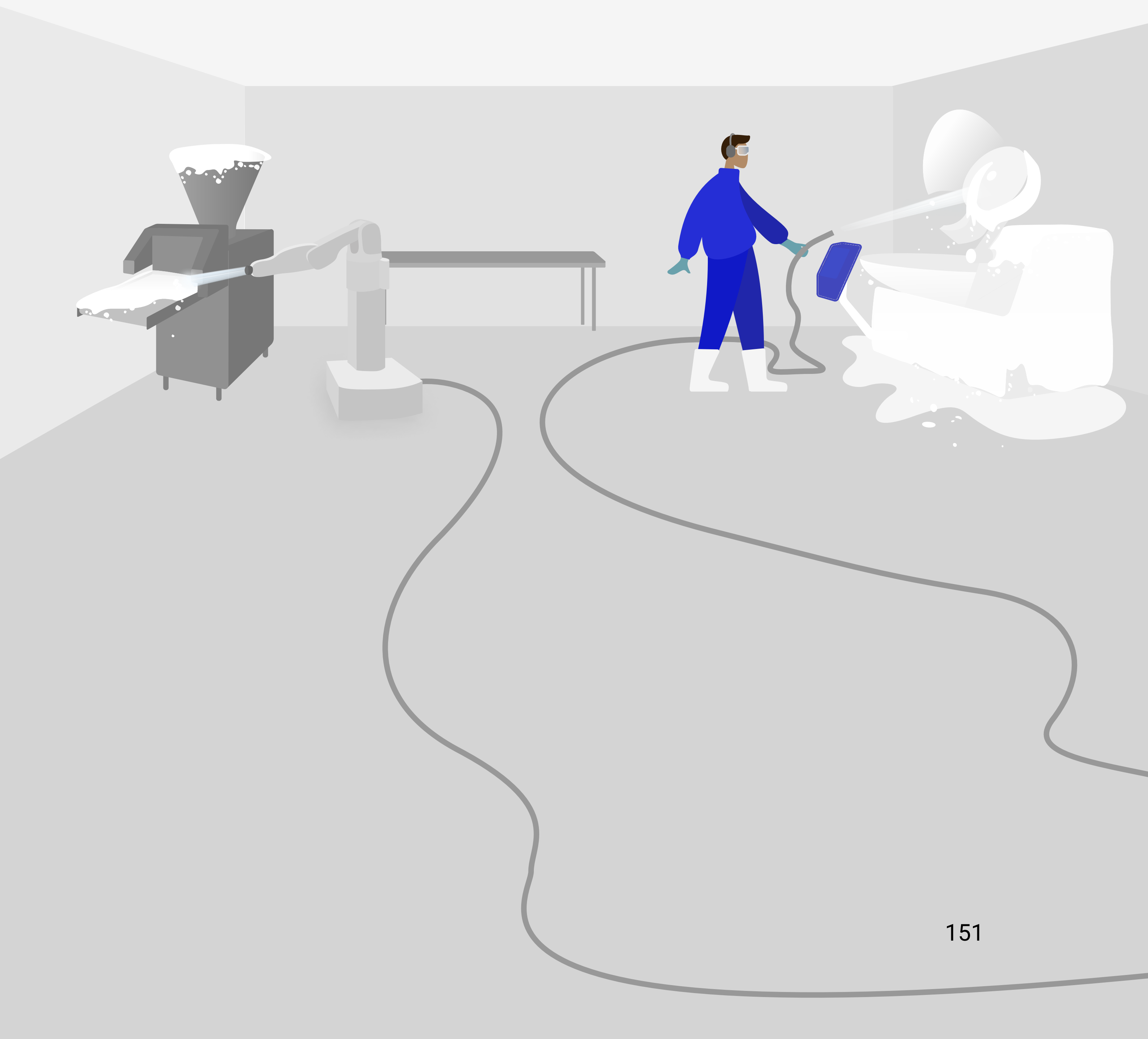
Salam rinses off the dirt that is left manually. Once all remains have been rinsed off, it is time for a final control by Salam. All visible dirt must be gone. The requirements for hygiene and cleanliness are extremely high in food plants as food quality and safety are crucial. This ocular inspection is therefore of great importance, and it is required that a human makes a final control of the cleanliness of each machine. He studies the machine in detail, and since there is no visible dirt left he marks coarse rinsing for this machine as done. Thereafter, he continues to the next machine to finish the coarse rinsing here too.

When the robot has finished rinsing off all areas it is capable of and Salam has completed and controlled the work, it is time to move on to the next step in the cleaning procedure and start to apply chemical foam. Salam confirms completion of the coarse rinsing using the AR menu in the smart safety glasses, and both the human and robot proceed to the next step of the cleaning program.

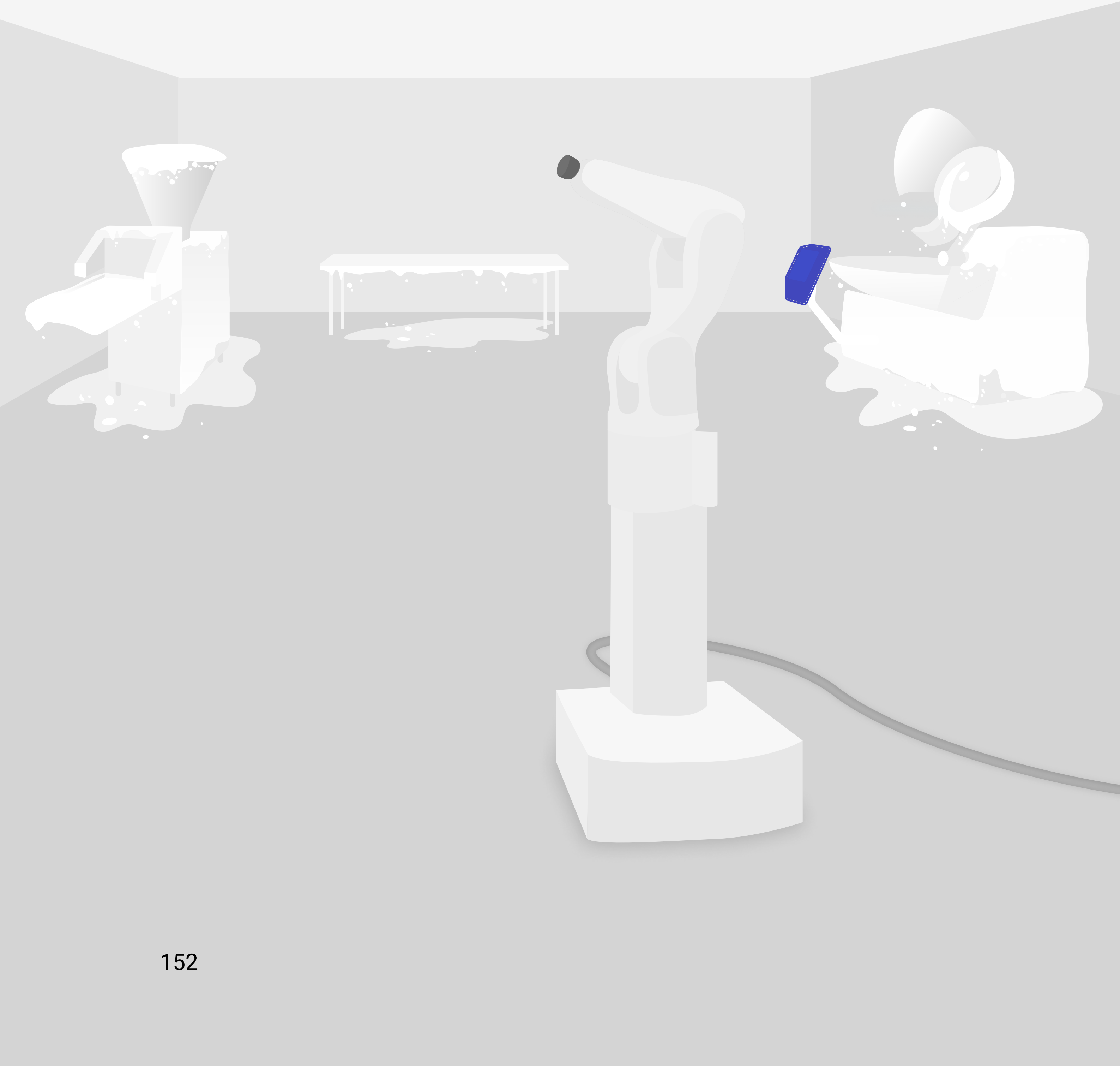
The robot begins to apply chemical foam, a procedure that is significantly quicker than the preceding step. When applying foam, it is important to ensure that all surfaces are properly covered with an even layer of foam that is not too thin, nor too thick. Just as with the coarse rinsing, Salam gets updates about the progress of the robot through his safety glasses and instructions for when and where he should add a final touch to finish the foam application.



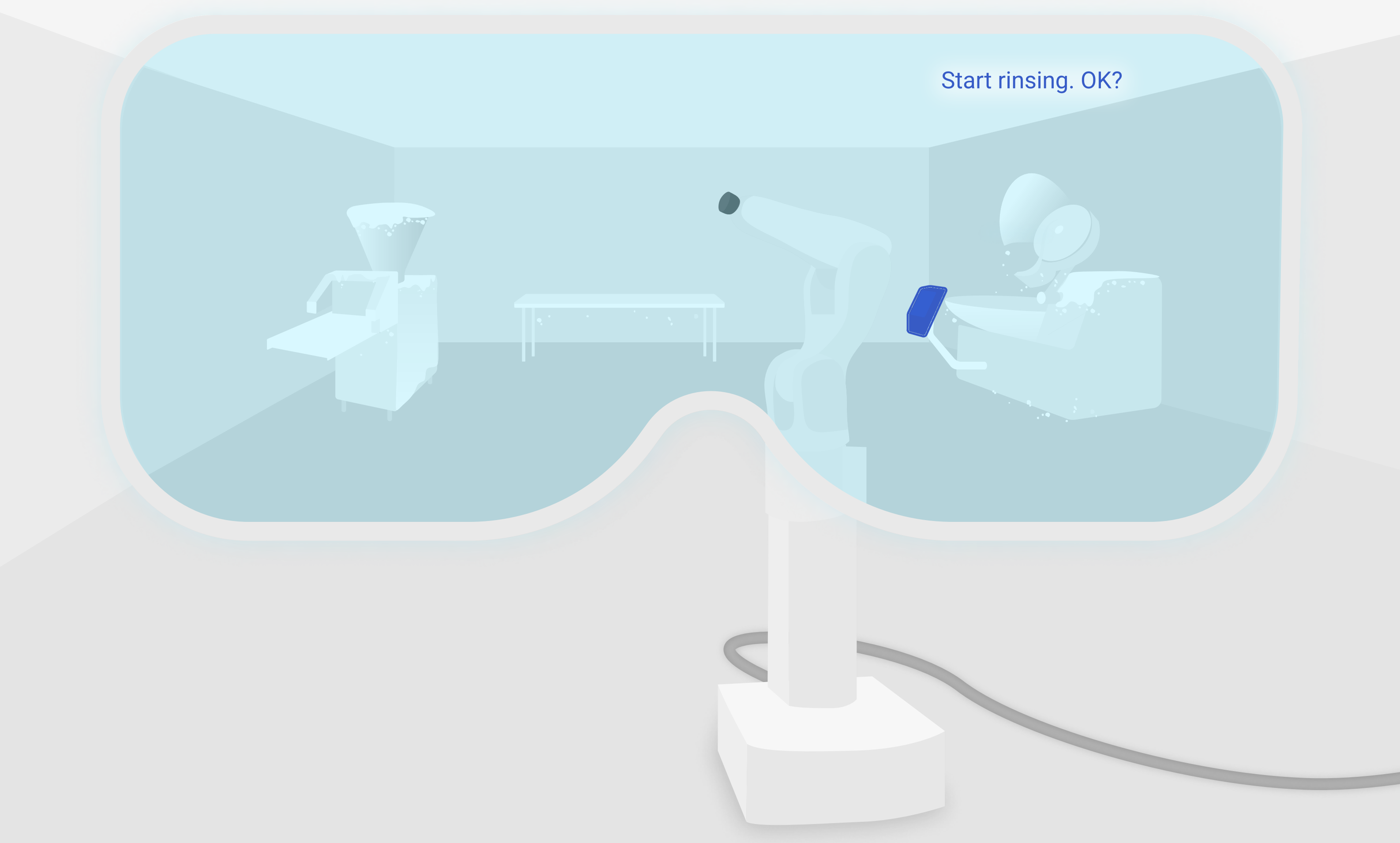
The robot starts by applying foam to the meat grinding machine, and Salam is given instructions to follow its path and cover the areas out of the robot's range. Systematically they cover the entire room with foam and Salam also doublechecks to ensure that all areas get covered.



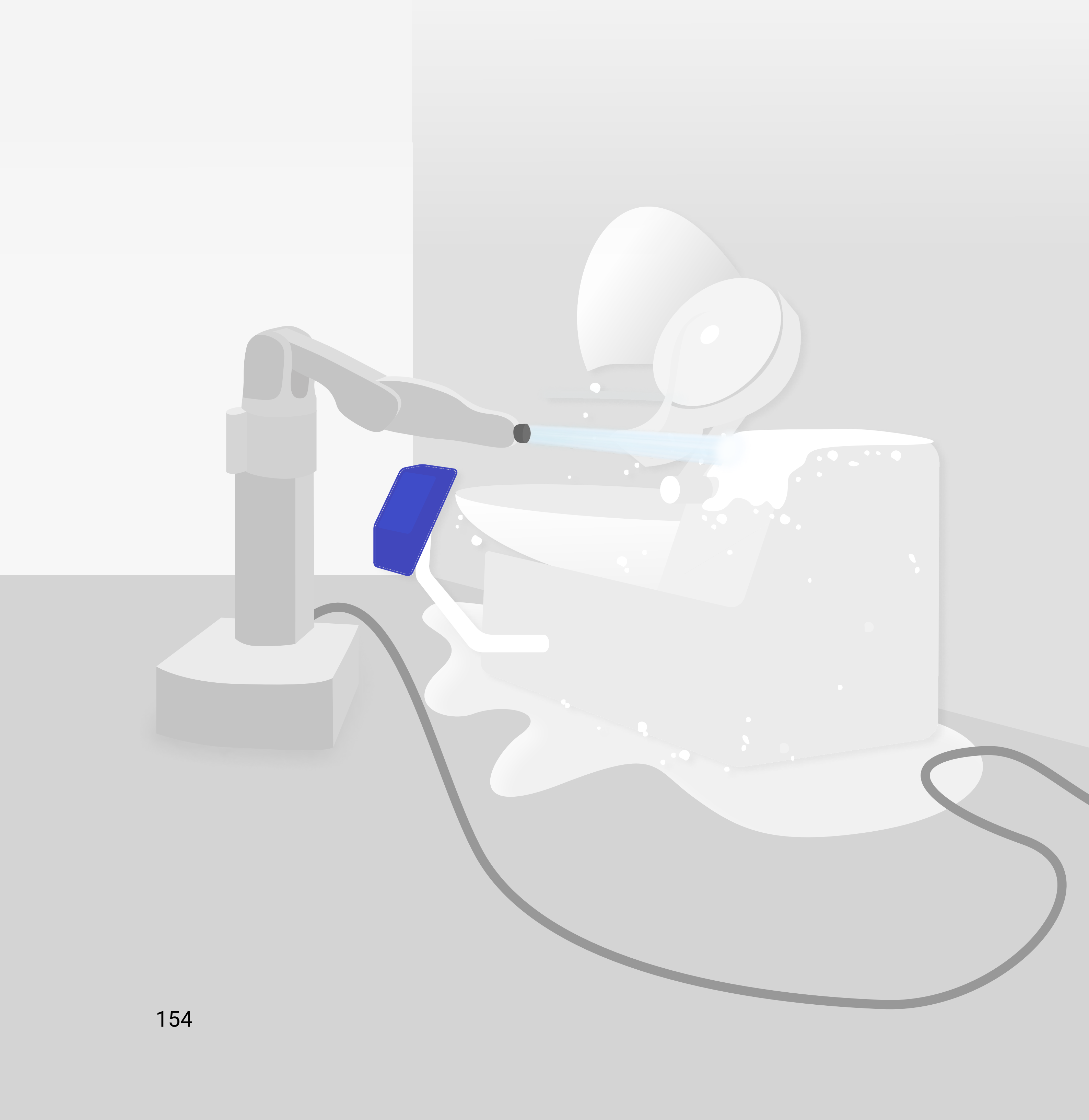
Once the foam has been applied, it should be left to react for at least 15 minutes. This time is necessary to give the chemicals time to react and resolve fat and other food remains. However, the foam should not be left too long either, as this can make it difficult to rinse off.



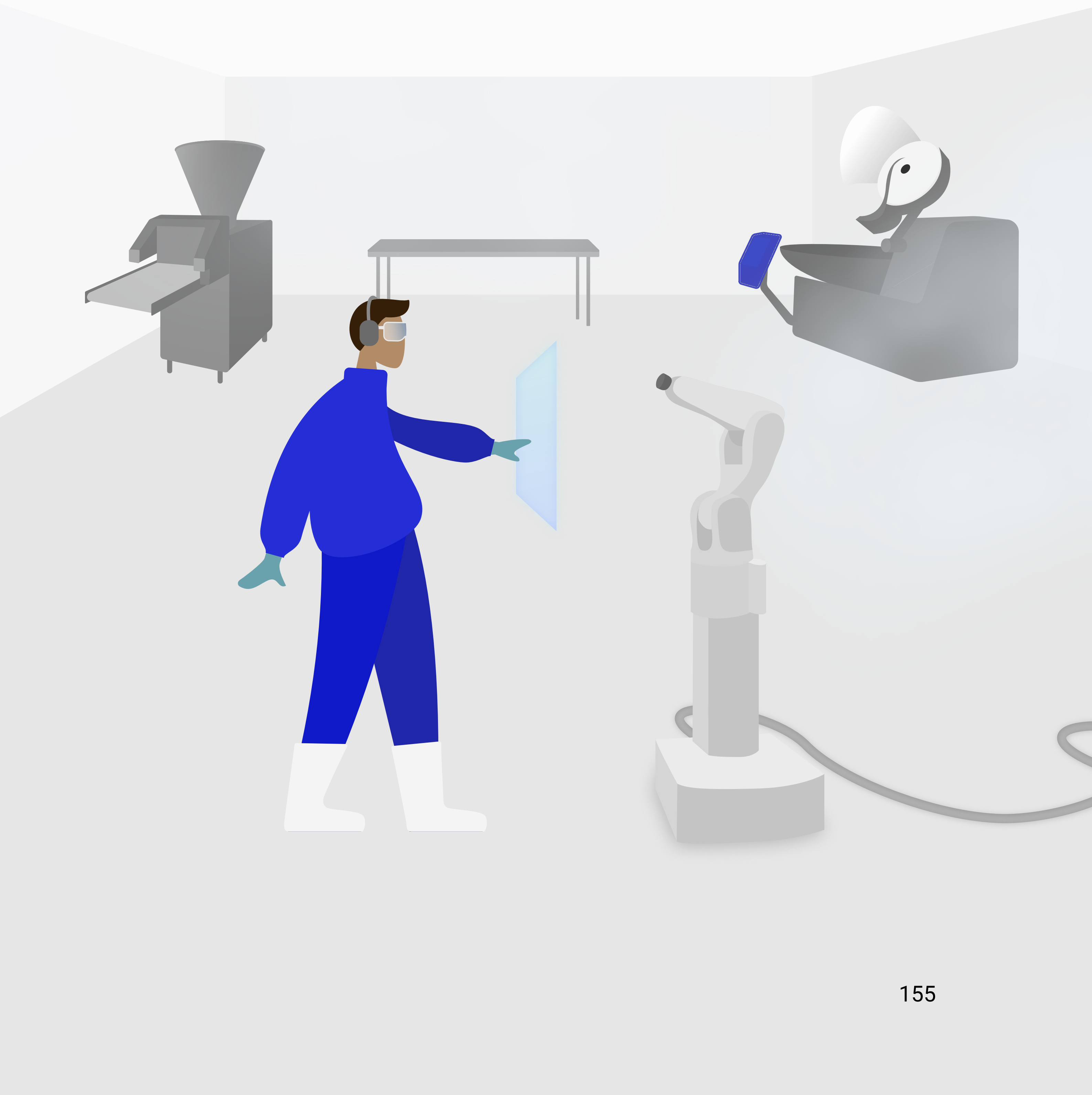
The robot keeps track of the time from when they started applying the foam, and when everything is covered, 15 minutes have passed. Salam gets a notification in the corner of his field of vision through his smart safety glasses, he is asked to confirm that the robot can start rinsing. Salam confirms that rinsing can begin and the robot starts to rinse off the foam.



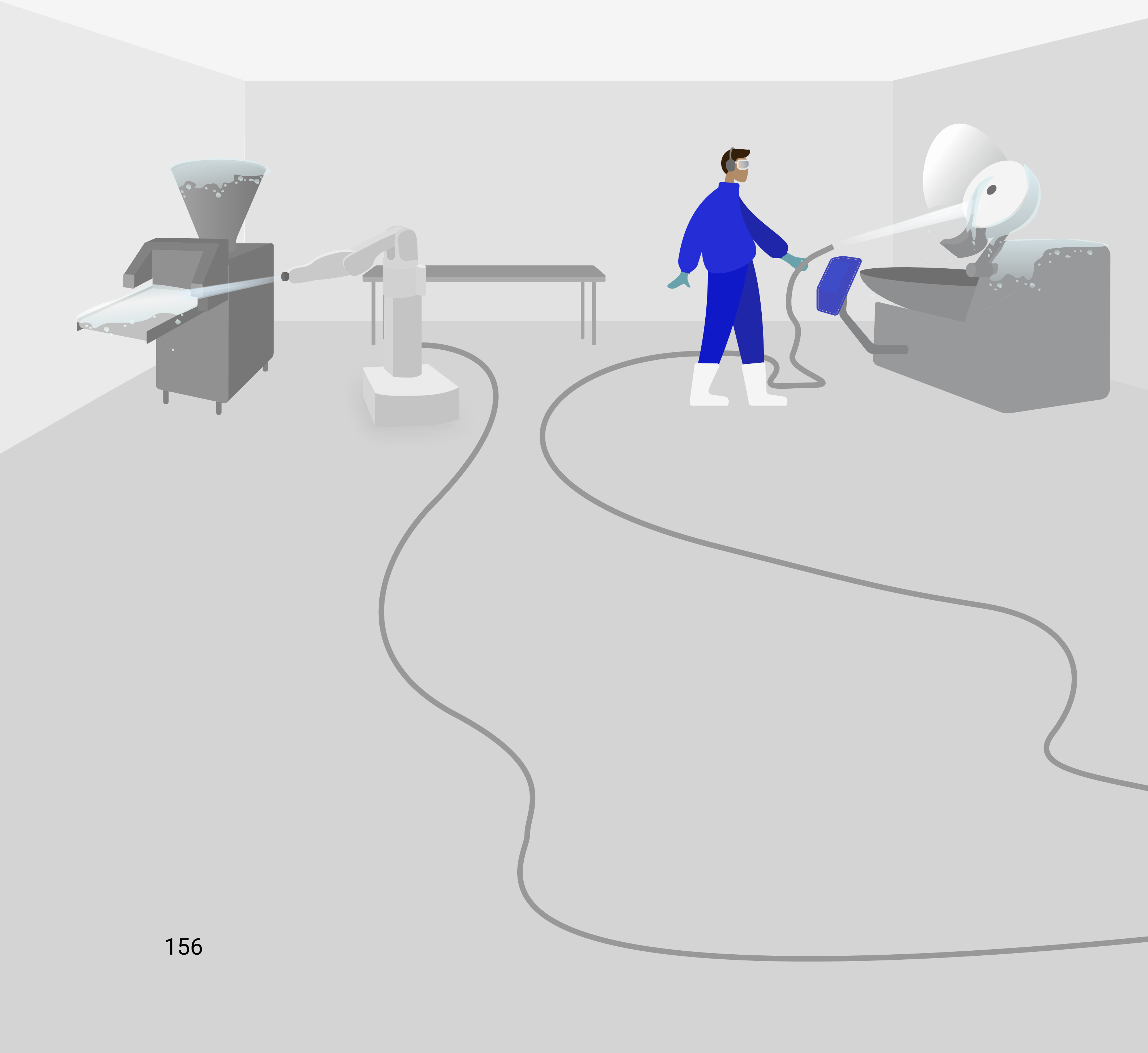
When rinsing off foam, the most important aspect is to make sure all foam is removed. The machines are rinsed off systematically in the same order as the foam was applied to them. The robot rinses off the majority of the foam. The robot thus once again needs support with making sure the areas outside its range are properly rinsed, and Salam is given instructions on where these areas are located through his smart safety glasses.



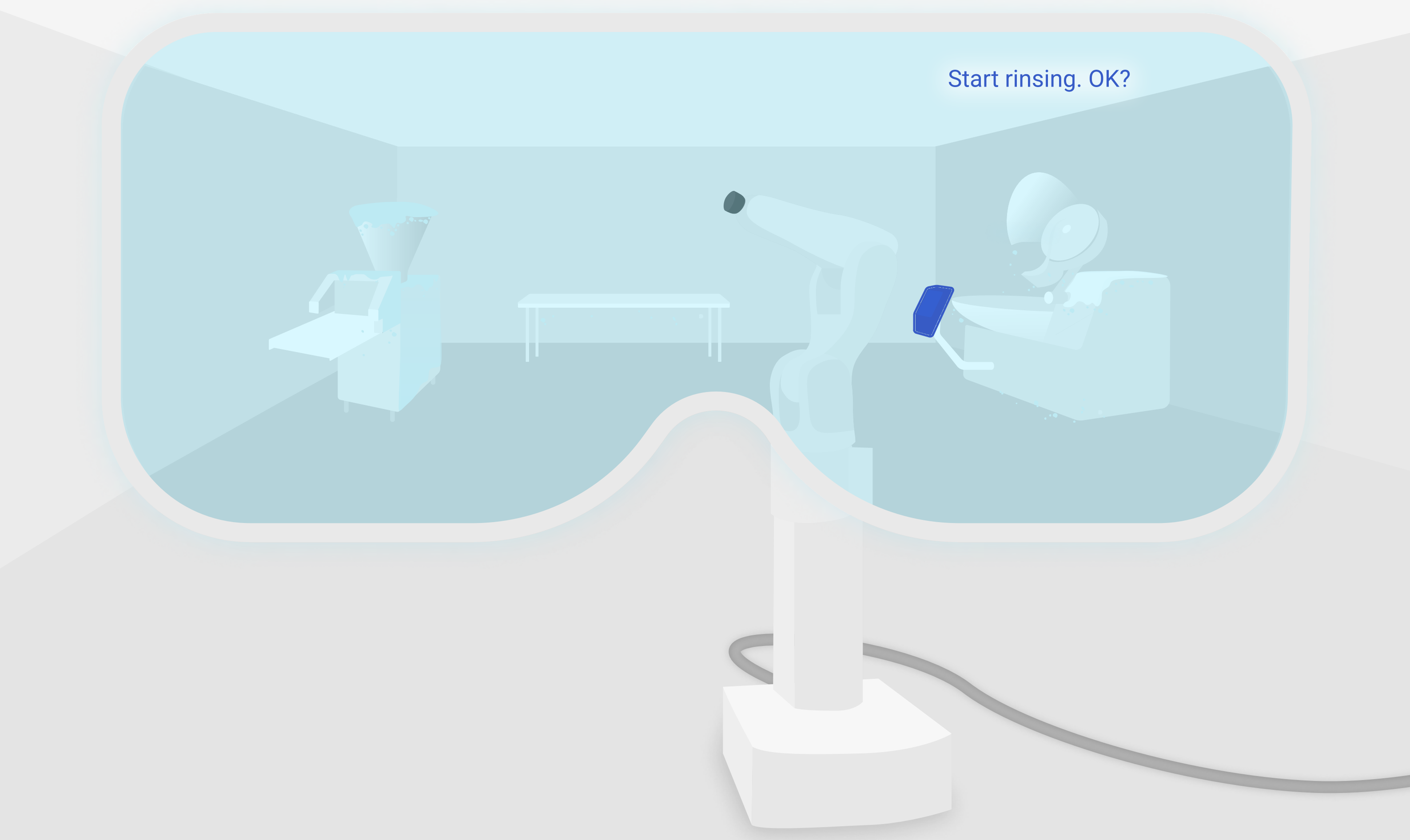
Salam rinses off the final remains and controls the final result. Salam checks each machine as it is cleaned so the system can help him keep track of what is done and what is left to do. Once the entire room has been rinsed, Salam confirms through the AR menu expanded from his smart safety glasses that the rinsing of the room is complete.



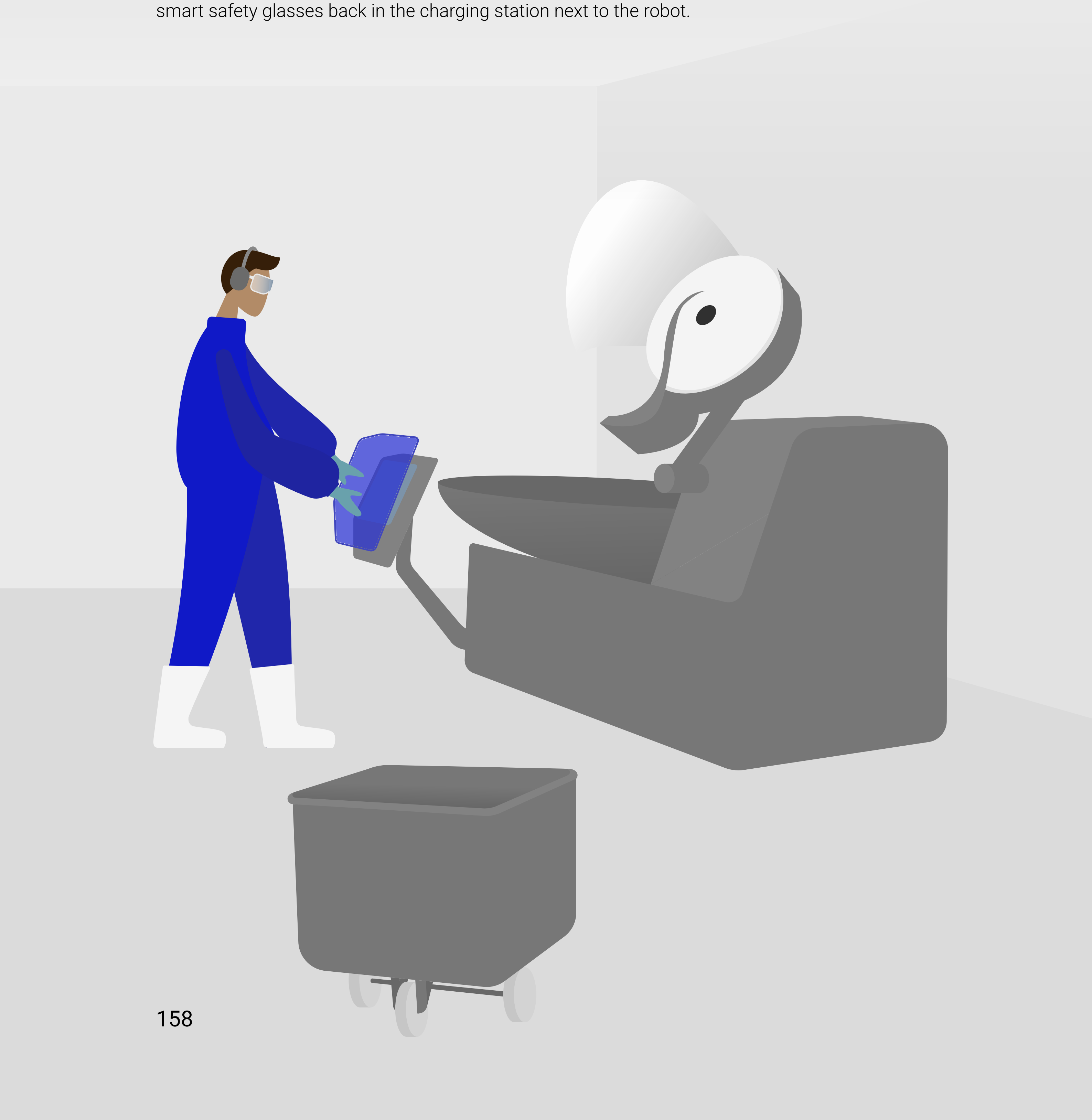
Finally, it is time for the last step of the cleaning procedure: applying disinfectant. This is a rather quick procedure. The goal is to make sure disinfectant is applied to all surfaces, and Salam collaborates with the robot in more or less the same way as he did when applying foam previously. The robot first applies disinfectant to most of the areas, and Salam completed the work by applying disinfectant to the zones marked as outside of the robot's range. When the disinfectant has been applied to every nook and cranny, it is left to react for about 10-15 minutes.



Similar to when applying foam the robot keeps track of the time and when everything is covered the time has passed. The robot asks Salam if it can start rinsing and informs Salam that it needs support from him. Salam confirms, and while the robot starts rinsing off the disinfectant Salam follows the instructions on where to support the robot with rinsing off. When everything is rinsed off, Salam confirms the completion of this step through the AR menu.



The production hall is now clean, and Salam calls upon a cleaning manager that gives the room a final check to validate the cleanliness. Salam also receives instructions through his smart safety glasses on how to restore the production hall and prepare it for production. He brings back the trolleys, buckets, and the small parts of machines that he removed in the beginning, removes plastic covers from machines, turns off the cleaning mode on the machines, and puts every door and part of the machines back to the position they had when Salam first arrived. The final thing Salam does before ending the shift is to disconnect the robot from the hose providing it with power and media. Thereafter he drives the robot back to the room where it is stored and puts the smart safety glasses back in the charging station next to the robot.



Working together with a robot has turned out to be not only quicker but also less tiring physically. He used to feel all drained after working a shift, but since the cleaning robot system was implemented he can clean a bigger area in less time with less effort. To Salam, the physical relief at work is a significant improvement. He is not the type that complains and he is not afraid to work hard either, but getting rid of the constant ache in his lower back is a great relief.

Since Salam wants to work efficiently and get the job done fast, he also really appreciates the time reduction enabled by the system of cleaning robots. Unlike a human colleague, a robot never gets tired, bored, or unfocused. In contrast to his initial preconceptions, the cleaning robot system has become a reliable partner in cleaning.

7
Discussion

This chapter covers a discussion about this master's thesis, including the process, the final results and future work.

7.1 Process

In accordance with the interaction design process and the fundamentals of UX design as described by Sharp et. al. [4], an understanding of the key user groups, their tasks and goals, and the environment is fundamental for this project. Thus, great emphasis was put on user studies during the process. To have many participants in a user study is in general better, according to Sharp et. al. [4], as the risk of finding random results that might not be statistically correct for the user group is reduced which in turn minimizes the risk of bias. However, the access to participants representing the intended key user groups was limited for multiple reasons during this project. The RoboClean Research Project is carried out in cooperation between five stakeholder companies. When recruiting participants for this study, the relationships between stakeholder companies and other companies had to be taken into account. Only customers or partners of the stakeholder companies could thus be contacted.

A recurring issue was also the fact that there exist no actual users of a system of cleaning robots like the one examined in this master. This was however an expected challenge, as the system of robots investigated in the RoboClean Research Project does not exist yet either. The data gathered about intended future key users and insights from users working in professional roles related to the future key user roles is however considered to be sufficient to claim that the descriptions are accurate based on what is known today. Nevertheless, it is of importance to highlight that the data gathered about users, their tasks and their work environment is based on what life is like today while actual users of the system of cleaning robots will be working decades from now, a fact that introduces an inevitable level of uncertainty.

When it comes to the cleaners, the participants in this study were all employees of the same cleaning firm. This homogeneity could introduce a risk of bias and topics missed out. For example, it was brought up by cleaners during interviews that the employees at this cleaning firm have better work conditions and appreciate their work more than food industry cleaners do in general. Hence, the data gathered from the cleaners might be biased towards a more positive view of the current work situation in food industry cleaning, in comparison the actual work situation in the industry overall.

Further, the majority of the cleaners interviewed were working in the same food plants as where the observations took place. If other cleaners working in other food plants had been interviewed, this could possibly have contribute to a more nuanced data gathering and reduced the risk of gathered data biased towards the circumstances at one particular workplace. On the other hand did the food plant observations contribute to the understanding of the cleaners work situations, and this understanding was deepened further when interviewing the people working there. Focusing on just a few food plants and the cleaners working there did thereby contribute to a deeper understanding of these cases.

Regarding the user studies related to system configuration, the challenges with no currently existing users became apparent. No professionals working with a similar system could be found, and the interviews were thereby held with people working in areas somewhat related to system configuration. None of these had experience of working with robots that are both mobile and collaborative though, and the description of the system configuration role and persona have thereby been formed based on sparse data where gaps can be found.

Ethics and Bias in User Studies

Ethical aspects must always be considered when involving users in a study. Based on what is discussed above regarding the user studies in combination with an amount of participants on the low side, there is a risk of bias. It is argued that a sufficient amount of participants was involved in this project, nevertheless, a bigger amount of participants could still have increased the reliability of the result further. According to Noble and Smith [78], bias in research reduces the validity and reliability of the result, and when the result is used in practice this issue can have further consequences. Ethical concerns thus arise when future users might be affected.

For example, biased data could lead to a biased view of the users' needs and the requirements this puts on a design. Ultimately, this could result in ethical issues with a biased design that does not meet needs and requirements of all its users. Bias and the ethical issues it introduces should thus always be minimized in research. On the other hand, one should also keep in mind that almost all research is biased to some extent according Noble and Smith [78]. Further, the participants involved in this study can be viewed as expert users. Since experts are rare in general it is not uncommon to only have a few expert users participating in a study. Their expertise in their field of knowledge also reduces the risk of bias to some extent, as they are per definition remarkably knowledgeable. Nevertheless, the concern of bias and possible ethical implications of this should be taken into consideration when using the result from this master thesis in future work.

Ethical Aspects of Introducing the System of Cleaning Robots to Food Plant Cleaners

Technological advancements have enabled robots to enter new markets and applications of robots in new settings such as the food industry, and robots keep encountering new user groups according to Beer et al. [26]. Resulting from this, robots will not only be in contact with users who have experience from working with robots, but also interact with users who have little or no previous experience of robots. The people working with cleaning in food plants today are an example of this. Today, they carry out a highly manual work when cleaning, and in general none of them know much about robotics. They are however the system operators of the future, expected to work side by side and collaborate with cleaning robots to make this system of robots work.

During interviews with this key user group, skepticism was expressed by many. Will the system even work in this challenging environment, or will cleaning robots just complicate things for the current cleaners? Additionally, fears of robots taking over their jobs were also expressed. This fear has also been noted in other projects where robots are introduced in new environments by for example Elprama et al. [28]. User acceptance, or rather lack of user acceptance, brings up ethical issues that must be considered when studying future possibilities of robots in environments where users have little experience. Further, user acceptance of robots is a crucial factor for successful human-robot interdependence [27, p. 709].

At any encounter with food plant cleaners, the assistant role of the robot was emphasized when presenting the RoboClean Research project to any user involved in the study. Despite this, a couple of cleaners still expressed concerns about having their jobs taken by robots when approaching the subject, giving rise to an ethical concern. When this occurred, the concern was met with an explanation of how human cleaners will remain crucial in making the robot cleaning system work at all. Further, it was stressed how the purpose is to improve the work situation of humans, and certainly not to eliminate them. It appears that this response reduced the anxiety among those users.

Nevertheless, the ethical concern of how the implementation of a system of cleaning robots is perceived by the current cleaners and how an eventual implementation could affect them remains and will continue to be relevant during the continuation of the RoboClean Research Project. Wallace [79] describes how the introduction of robots influences the daily life of people, and how many studies looking into the ethical aspect of robotics has been conducted. An implementation of a system of cleaning robots would certainly make the current cleaners to change the way they behave and how do their work. It would certainly affect their daily life, thus introducing ethical aspects that must be considered when involving and designing for this user group.

7.2 Results

The purpose of this master's thesis was to explore how the system configurators and system operators should interact with a system of cleaning robots. In order to successfully answer to the research question stated initially, the results of this master thesis should describe how to design this interaction between the key user groups and the system of cleaning robots. This has been done through the design recommendations. Further, the results should also provide insights on how these design recommendations could support the users' experience during configuration and operation. While the design recommendations also answers to this in general terms, the scenarios further exemplifies how the design recommendations could be applied and the User Experience this would result in through a narrative. While the design recommendations constitutes a useful and concise guide for further interaction design in this project, the scenarios also support future work within interaction design as they make it easier to envision and empathize with the key users in this future context, their work situation, and their needs and requirements for a system of cleaning robots. In summary, the research question has been successfully answered with the results presented.

Prati et al.[12] describes how research within the field of Human-Robot Collaboration often and fails to cover aspects of human-centered design. They see a need of considering human factors, more specifically the User Experience in Human-Robot Interaction. In the future of the RoboClean Research Project, the design recommendations can become a tool for this. This is the motivation behind the statement in the section above, claiming that the design recommendations constitutes a useful and concise guide for further interaction design in this project. The design recommendations have been developed using interaction design methods, deeply anchored in user research and derived with consideration to User Experience. Application of these design recommendations thus supports aspects of Human Centered Design, which promotes overall improved Human-Robot Interaction [12].

One could argue that the design recommendations answers to the research question on their own, so why are the scenarios included in the final result too? The scenarios play an important role in complementing the design recommendations by clarifying their purpose and meaning. The scenarios are narrations describing a possible future where food plant cleaning is performed by humans in collaboration with robots, and where these design recommendation have been applied. According to Malpass [5], narratives is useful in speculative design as they provide a vivid description of how a design concept is used by a specific user in a certain context. This enables users without significant technical expertise or design experience to emphasize and create an understanding of a futuristic design concept.

With the scenarios presented in this report, the aim is further to enable speculations about technologies and future design concepts, corresponding to Auger's [7] description of speculative design. The description of how the system of robots will function is however rather an accurate rendering of what is known about the technical structure of the system and its abilities and limitations today. The description of what the RoboClean Configurations Software is widely based on what the stakeholder companies, and in particular FCC, expects the software to be like in the future. Similarly, the description of the cleaning robots and what they can and cannot do is widely based on information from ABB. Accordingly, these technical aspects are rather reasonable assumptions about the future based on expert knowledge. Then, what was speculative in this result? The speculation in this design scenario concerns the interaction mode. As described in the introduction, extremely little attention have been paid to the mode of interaction within the RoboClean Research Project, despite the necessity of human interaction to make the system work at all. Within the frames of the systems currently known technical abilities and limitations, this master's thesis presents speculations on how user interaction with this system of cleaning robots could take place. Grounding the speculations in user needs and an understanding of the food plant context, we argue that the result should be viewed as a probable prediction of a plausible future.

As stated initially under Delimitations, Section 1.4, we have taken the technical limitations of the RoboClean Configuration Software as well and the limitations of the cleaning robot that have already been defined within the RoboClean Research Project today into consideration. During data gathering from stakeholder companies, we learned about how they expect the future system of cleaning robots to work based on the research done so far. We argue that by using this as the starting point for further work within this project, the trustworthiness of the result increases. Since the scenarios describing the future builds on what has already been established, the likelihood of realization of these scenarios in a future 10 years from now appears greater than if these limitations would have been overlooked. On the other hand, one could argue that these delimitations might also have biased and limited the result towards a current technological capacities. If we would have allowed ourselves to speculate not only around interaction modalities, but also around the entire design of the system of cleaning robots, the result would certainly have looked different and so would also the contribution to the RoboClean Research Project. Nevertheless, it is our conviction that this thesis has shed a light on new areas and opportunities for future work on designing interaction modalities within the continuation of the RoboClean Research Project. Further, to the best of our knowledge the introduction of speculative design as an approach to develop ideas and concept for interaction has also made a valuable contribution to the RoboClean Research Project.

Ethics and Gender Bias

It seems important to bring up an ethical discussion on the topic of gender neutrality here. The key user roles described through personas and scenarios all have a defined gender, whereof three personas are men and only one is a woman. Additionally, the main characters of both the scenarios presented in the result section are male. Accordingly, the descriptions of the key user roles are predominantly male.

This is not a coincidence, nor a decision based on bias. The discussion of gender neutrality was brought up while working with personas as well as scenarios, and a conscious decision was made to base the gender of the personas on the gender representation among the two user groups. Since cleaning in food plants is an industry with a distinct male majority among the workers, 2 out of 3 personas for system operators became men. Similarly, there is also a clear majority of men among people working with robot system integration and configuration and accordingly, the system configurator became a man.

This predominantly male representation in the description of the key user roles does however introduce an ethical concern. Lopes and Voegel [80] describes how gender bias in tech and development processes can lead to prioritization of the needs of men, while the needs of women becomes disregarded. Further, their study indicate that traditional gendered personas result in less gender-inclusive design in comparison to gender neutral personas.

Thus, the decision to use mainly male characters when describing the key user roles introduces an increased risk of missing out on needs associated with female or non-binary users. On one hand, it appears sensible to reproduce a picture of the key user group that is as similar to reality as possible. On the other hand, the gender distribution might have changed in the future where these scenarios are to take place. Nonetheless, the goal should be to account for all user needs, male as well as female and non-binary. To reduce the risk of gender bias in a continuation of this project, awareness of this risk is significant when basing further work on the personas and scenarios presented in this report.

7.3 Future work

This study has been carried out with a limited user group as discussed above in section 7.1. All the participants working with cleaning were employed by the same cleaning firm, and in addition there was a distinct male majority with regards to gender distribution. To reduce the risk of bias and strengthen the validity of the user research in the future, it is encouraged to conduct additional user studies encompassing a more diverse group. This could include for example participants working on different food plants and for different companies dealing with system configuration. Inclusion of more participants with more diversity would validate the results of this master's thesis and possibly find additional considerations to keep in mind when designing for this environment and user group. A lesson learned during the work with this master thesis is also to reach out to participants early, since finding time in their work schedule to conduct user studies is not always easy. Further, it is good to make sure to have an extra time buffer for user studies, since appointments sometimes get postponed for different reasons. This lesson learned is something to keep in mind within future work.

Moreover, this project has studied a case where only one robot and one cleaner work together. This delimitation has influenced the entire procedure and is also reflected in the results. It is however likely that there could be more than one robot working in the same food plant, and there could also be multiple cleaners collaborating with the same robot. This would affect the work for both the system configurators and operators. If the system will include multiple system operators and/or robots in the future, it is likely that some aspects of the findings presented in this report might need to be reconsidered. Looking into this within future work will therefore be important.

As this master's thesis has been conducted during the early stages of the RoboClean Research Project, no actual robot yet exists. Participants in this study have therefore been limited to trying to imagine what it would be like to interact with a robot. However, to ensure a good User Experience when interacting with the system in the future, tests with an actual robot are of importance and should be carried out when possible. A lesson learned is also the challenges with discussing speculative design concepts and future technical solutions for Human-Robot Collaboration with users that have limited technical experience. For example, when discussing attitudes and thoughts around working together with a robot with the cleaners, we found that we had to be active in our roles as interviewers and moderators to guide the conversation towards interaction modalities in order to not get stuck on discussing only the capabilities of the cleaning robot. Further, since the RoboClean Research Project still has a long way to go possibly delivering a system of collaborative robots, the work within this master's thesis and the concepts developed are speculative as well as conceptual rather than developed in detail. Within future work, it does however seem natural to develop refined design concepts and present these with higher fidelity, to be able to further investigate and evaluate aspects of interaction design and user experience. Further, introducing a system like this to the market requires a big amount of work in the more detailed design for the interaction and UI, as well as physical design of the interaction modalities.

8
Conclusion

The RoboClean Research Project was initiated to investigate the possibility to support human cleaners with a system of mobile and collaborative cleaning robots, with the underlying goal of making the cleaning procedure more effective, efficient, reliable, and sustainable. This system of cleaning robots is pioneering within its field, and no research on User Experience has yet been conducted. This master's thesis, therefore, aims to identify the key users of this future system of cleaning robots, and further speculate on how the interaction with this system could be designed to support a good User Experience in a future 10 years from now. The following research question was thus formulated:

How should the interaction with a system of cleaning robots be designed to support the users' experience during configuration and operation?

To answer this question, research through design with a speculative design approach has been carried out. Initially, the focus was thus put on data gathering in order to gain an understanding of the system of robots and its intended users, their tasks in relation to the robot system, and the food plant context. Data from observations and interviews were analyzed using thematic analysis, and the findings indicate that the environment inside a food plant is challenging from an interaction design perspective. Further, the people working in food plant cleaning have in general limited technical knowledge and no experience of robots. The people working with robot system integration on the other hand possess knowledge in multiple technological fields, but the experience of configuring mobile and collaborative robots is yet very limited.

During the subsequent steps of the design process, the findings from data gathering were further processed resulting in a system map defining the different parts of a system of cleaning robots, personas defining the key user roles, and descriptions of the future tasks and workflows user journeys and scenarios. Thereafter, the interaction between key users and the robot system was explored. Regarding system configuration, a suggested procedure for system configuration was developed and presented using a Heuristic Task Analysis. Regarding system operation, four different speculative design concepts were developed and presented using storyboards.

The Heuristic Task Analysis and the storyboards were subsequently evaluated with intended future key users, designers, and stakeholder companies. Finally, the 11 design recommendations for interaction design presented below could be derived based on the lessons learned during all preceding steps.

Design recommendations for interaction during system configuration:

DR 1	Provide optimized defaults, but allow for changes
DR 2	Support the user with decision making
DR 3	Support reuse of parts from other cleaning programs
DR 4	Provide the user with an overview, but allow examination of details
DR 5	Encourage a Human Centered Design approach

Design recommendations for interaction during system operation:

DR 6	Adapt Human-Robot Interaction for the work environment
DR 7	Adapt Human-Robot Interaction for the work tasks
DR 8	Adapt Human-Robot Interaction for the target user group of system operators
DR 9	Enable remote Human-Robot Interaction
DR 10	Design for a seamless shift from cleaning to interacting with the system
DR 11	Design for perceived control and safety

How the interaction could be designed was also further demonstrated through two future scenarios. The design recommendations provide a first step towards a good interaction with the system of cleaning robots. However, more work within User Experience remains to be done. Looking into cases with multiple cleaning robots and multiple system operators is encouraged within future work. Further, research with a bigger and more diverse user group as well as tests with an actual robot and a high fidelity prototype to interact with would be beneficial to ensure a good User Experience. To conclude, the 11 design recommendations presented in combination with the future scenarios answer to how the interaction with a system of cleaning robots should be designed to support User Experience during configuration and operation. There exists research on other systems of cleaning robots already, as well as research from different parts of the Human-Robot Interaction field, but no User Experience oriented research on systems of cleaning robots in the food industry has ever been done before. In addition, no study looking into the User Experience of mobile, collaborative cleaning robots has ever been done before owing to the novelty of this concept. Based on this, we finally conclude that the results presented in this report have made a contribution to new discoveries within this field of research. Further, the results presented in this report also lay a foundation for future work on User Experience within this area.

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A

Observation Plan Food Plants

Time & Space

- In what order are different activities done and how often do they change the activity?
- How is the factory hall organized? Are there different zones in the factory?
- Is there space enough for the robot to move around?

Objects

- What are the physical objects present—for example, machines, food, cleaning equipment?
- How do they interact with the objects?
- Do they use any technical devices/aids?
- How do things in the factory look, sound and smell?

Social Actors & Interactions

- How many cleaners are there?
- Who are the cleaners? Gender, age, ethnicity etc.
- What language(s) do the cleaners speak?
- What is the social status of/relationships between different people in the factory?
- What do the cleaners do, and how do they behave?
- How do they communicate? Who communicates with whom, how, when, and where?
- What topics are talked about, in what tone? (Before cleaning? During? After?)
- Are there any special words or phrases characteristic for the group?

Routines

- What routine tasks are there?
- What are more rare, unusual, or unexpected tasks?
- Are there any individual differences in behavior or operation?

- Describe how specific cleaning tasks are done
- How do they know when a task/subtask is finished?
- How is a cleaning task commented upon and discussed? (tough/difficult, fun/easy, etc.)

B

Interview Questions Cleaners

As this project was conducted in Sweden, the interviews were held in Swedish.

Godkännande av medverkan i studien samt inledande frågor

Innan frågor ställdes ombads deltagarna att läsa igenom vilket och ge sitt godkännande för att vara med i studien. Därtill fyllde dom i följande formulär:

- Hur gammal är du?
  - ☐ 18-29
  - ☐ 30-39
  - ☐ 40-49
  - ☐ 50-65
  - ☐ 65+
- Vilken kön identifierar du dig som?
  - ☐ Man
  - ☐ Kvinna
  - ☐ Annat/Vill ej ange
- Vilket är ditt modersmål?
- Vilka andra språk kan du?
  Ange även en siffra 1-5 för att visa hur bra du kan språket.
  1 = Du kan göra dig förstådd och föra enklare konversationer
  5 = Du pratar språket flytande och förstår språket perfekt
- Vilken är den högsta nivå av utbildning som du har slutfört?
  - ☐ Grundskola
  - ☐ Gymnasium
  - ☐ Yrkeshögskola
  - ☐ Universitet/Högskola
  - ☐ Annat:

Inledande frågor om städaren

- Berätta lite om dig själv?
- Hur länge har du jobbat med rengöring?

- Har du någon utbildning specifikt för det här jobbet?
- Hur kom du in i den här yrkesrollen?
- Vad har du jobbat med tidigare?

Frågor kring städning

- Berätta om hur det går till när ni städar (steg för steg)
  - Städas hela lokalen samtidigt?
  - I vilken ordning görs de olika städmomenten?
  - Hur många är ni som städar?
  - (Om fler än en) Hur delas arbetet upp?
  - (Om fler än en) Hur kommunicerar ni med varandra under arbetet?
- Vad tycker du om arbetet som städare i matfabriker?
  - Vilka är de största fördelarna med ditt arbetet?
  - Vilka är de största nackdelarna med ditt arbete?
  - Vad är svårt med ditt arbete?
  - Vilken arbetsuppgift är tyngst/jobbigast/värst?
    - Hur löser ni den uppgiften i dagsläget?
  - Finns det något som du skulle vilja ändra på i ditt arbete?
- Städar du/har städat i fler fabriker än denna?
- (Om personen städar i fler fabriker) Hur skiljer det sig mellan olika fabriker du städar på?

Frågor kring teknik

- Använder du någon teknik när du jobbar?
  - Någon teknik som hjälpmedel i arbetet? Exempelvis diskmaskin, Lagafors rengöringssystem, annan teknisk rengöringsutrustning?
- Hade du velat ha fler hjälpmedel av något slag?
- I så fall vad för hjälpmedel? Till vilka arbetsuppgifter?
- Lyssnar du på musik, pod eller liknande när du jobbar?

Frågor kring att arbeta med en robot

- Hur skulle du känna kring att ha en robot som assisterar dig i arbetet?
- Vilka arbetsuppgifter skulle du vilja att roboten hjälpte dig med?
- Vad ser du som de potentiellt största fördelarna med en assisterande robot?
- Vad ser du som de potentiellt största nackdelarna med en assisterande robot?
- På vilket sätt skulle du föredra att roboten kunde ge dig information under städningen?
- Hur skulle du vilja kunna kommunicera tillbaka till roboten/styra roboten?

C

Interview Questions System Integration

As this project was conducted in Sweden, the interviews were held in Swedish.

Godkännande av medverkan i studien samt inledande frågor

Innan frågor ställdes ombads deltagarna att läsa igenom vilket och ge sitt godkännande för att vara med i studien. Därtill fyllde dom i följande formulär:

- Hur gammal är du?
  - ☐ 18-29
  - ☐ 30-39
  - ☐ 40-49
  - ☐ 50-65
  - ☐ 65+
- Vilken kön identifierar du dig som?
  - ☐ Man
  - ☐ Kvinna
  - ☐ Annat/Vill ej ange
- Vilket är ditt modersmål?
- Vilken är den högsta nivå av utbildning som du har slutfört?
  - ☐ Grundskola
  - ☐ Gymnasium
  - ☐ Yrkeshögskola
  - ☐ Universitet/Högskola
  - ☐ Annat:

Inledande frågor om personen

- Berätta lite om dig själv?
- Berätta lite om ditt jobb?
- Hur länge har du jobbat med systemintegration?
- Har du någon utbildning specifikt för det här jobbet?

- Hur kom du in i den här yrkesrollen?
- Vad har du jobbat med tidigare?

Frågor kring systemintegration & robotik

- Hur går det till när man integrerar ett nytt system?
  - Förberedelser?
  - I mjukvara?
  - På plats?
  - Efteråt?
    - Installerar och sen klar, eller återkommer dom till samma ställe och justerar saker?
  - Hur lång är processen?
- Vilka kunskaper behövs för att integrera ett system?
  - Robotik/Maskiner?
  - Programmering?
  - Mjukvaror?
  - Annat?
- Behövs någon specifik bakgrund?
  - Akademisk Utbildning eller Arbetslivserfarenhet?
  - Är båda möjligt?
  - Hur lång tid tar det att lära sig arbetet?
- Vad behövs för att integrera ett system?
  - Kring CAD-modeller?
  - Kring Robot?
  - Kring rörelser/hastighet/mm?
- Har du någon erfarenhet av mobila robotar?
  - Vilka krav ställer det vid systemintegrationen?
  - Utmaningar?
  - Möjligheter?
- Har du någon erfarenhet av kollaborativa robotar?
  - Vilka krav ställer det vid systemintegrationen?
  - Utmaningar?
  - Möjligheter?
- Har du någon erfarenhet av kollaborativa mobila robotar?
  - Vilka krav ställer det vid systemintegrationen?
  - Utmaningar?
  - Möjligheter?

D

Evaluation Questions System Integration

Keep in mind that this is a speculative design concept, i.e. feel free to speculate freely about the future

1. General thoughts about this step by step description?
2. Are there any steps that we have missed?
3. Are there any steps that you think are redundant?
4. Are there any steps that you think should be carried out by another person/software?
    - How many people do you think would be involved in doing a job like this?
5. Are there any steps that will be more difficult/challenging to carry out?
6. Do you see any need for changing the order of tasks
7. How much time do you think the different steps will take? How much time do you think the entire process will take?
8. Are there any tasks here that the software will not be able to handle?
    - Can the programming into HRI be done in the software? How could that be done?
9. Is there any task that you think is done manually now, but could be automized, now or in the future?
10. How could optimization of division of work between human and robot be taken into account?

E

Storyboards

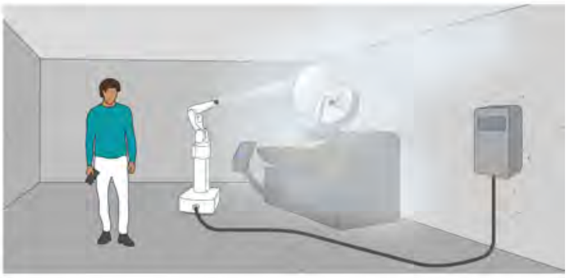
This appendix includes the storyboards describing the four concepts.

Mobile Device

Den här fabriken ska rengöras. Här jobbar städaren Sam, och han kommer genomföra arbetet med hjälp av en robot.

Till att börja med måste Sam förbereda rummet genom att plocka bort alla lösa föremål och koppla in roboten till pumpstationen med vatten och kemikalier.

När allt är förberett tar Sam fram den mobila kontrollen som styr roboten från sin ficka. Sam väljer vilket städprogram som ska köras, och får instruktioner för vilka förberedelser som behöver göras innan programmet kan startas. Sam har redan förberett allt, så han bekräftar det och startar roboten.



Roboten börjar med grovspolningen. Under tiden som den jobbar passar Sam på att gå över till rummet bredvid och skölja av några vagnar.

Efter 30 minuter har roboten spolat av alla ytor som den kommer åt. Det finns dock lite smuts kvar som inte roboten kan hantera, så roboten pausar sitt arbete och en notis om det skickas till städaren.

Sam känner hur den mobila kontrollen vibrerar och hör ett notis-ljud ifrån sin ficka. Han kollar på den mobila kontrollen och går tillbaka till rummet med roboten.

Med hjälp av AR kan Sam nu se vilka ytor som roboten inte kunnat rengöra.

Sam sköljer bort den synliga smuts som finns kvar.

När Sam är klar med grovsköljningen gör han en okulär inspektion för att se så allt ser bra ut. Alla ytor ser rena ut, och det är med andra ord dags för att gå vidare och lägga på skum.

För att gå vidare till nästa steg i städprogrammet tar Sam upp den mobila kontrollen igen och bekräftar att grovsköljningen är avslutad. Roboten påbörjar då skumpåläggningen.

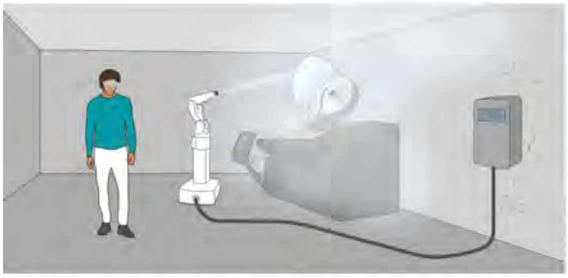
Smart Glasses

Den här fabriken ska rengöras. Här jobbar städaren Sam, och han kommer genomföra arbetet med hjälp av en robot.

Till att börja med måste Sam förbereda rummet genom att plocka bort alla lösa föremål och koppla in roboten till pumpstationen med vatten och kemikalier.

När alla förberedelser är klara aktiverar Sam sina smarta skyddsglasögon som används för att styra roboten. För att öppna menyn trycker han på sidan av glasögonen.

En meny projiceras i AR. Sam väljer vilket städprogram som ska köras och får instruktioner för vilka förberedelser som behöver göras innan programmet kan startas. Sam har redan förberett allt, så han bekräftar det och startar roboten.



Roboten börjar med grovspolningen. Under tiden som den jobbar passar Sam på att gå över till rummet bredvid och skölja av några vagnar.

Efter 30 minuter har roboten spolat av alla ytor som den kommer åt. Det finns dock lite smuts kvar som inte roboten kan hantera, så roboten pausar sitt arbete och en notis om det skickas till städaren.

Sam hör en notifikation och ser en liten röd lampa tändas i perferin. Han går tillbaka till rummet med roboten för att se vad han behöver göra.

Med hjälp av AR kan Sam nu genom sina glasögon se vilka ytor som roboten inte kunnat rengöra.

Sam sköljer bort den synliga smuts som finns kvar.

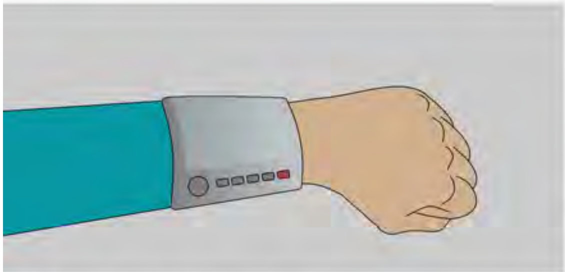
När Sam är klar med grovsköljningen gör han en okulär inspektion för att se så allt ser bra ut. Alla ytor ser rena ut, och det är med andra ord dags för att gå vidare och lägga på skum.

För att gå vidare till nästa steg i städprogrammet bekräftar Sam att grovsköljningen är avslutad genom att klicka på en knapp på sidan av glasögonen. Roboten påbörjar då skumpåläggningen.

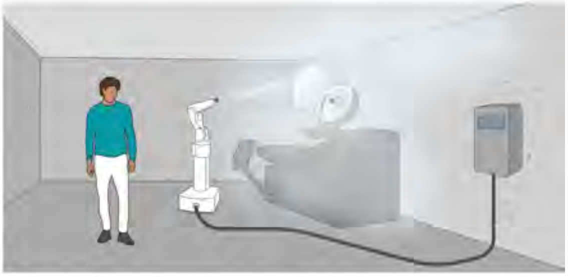
Wrist Device

Den här fabriken ska rengöras. Här jobbar städaren Sam, och han kommer genomföra arbetet med hjälp av en robot.

Till att börja med måste Sam förbereda rummet genom att plocka bort alla lösa föremål och koppla in roboten till pumpstationen med vatten och kemikalier.

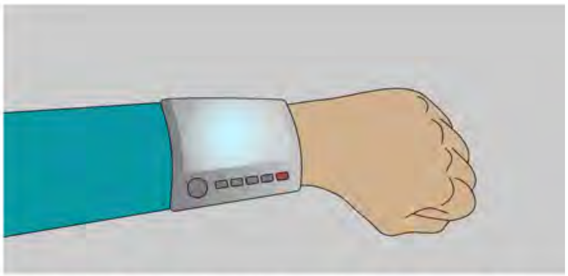


När allt är förberett väljer Sam vilket städprogram som ska köras på sin handledskontroll. Han får då instruktioner för vilka förberedelser som behöver göras innan programmet kan startas. Sam har redan förberett allt, så han bekräftar det och startar roboten.



Roboten börjar med grovspolningen. Under tiden som den jobbar passar Sam på att gå över till rummet bredvid och skölja av några vagnar.

Efter 30 minuter har roboten spolat av alla ytor som den kommer åt. Det finns dock lite smuts kvar som inte roboten kan hantera, så roboten pausar sitt arbete och en notis om det skickas till städaren.

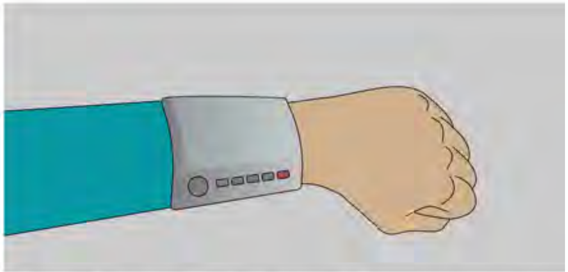


Sam känner hur hans handledskontroll vibrerar hör samtidigt en notifikation. När han tittar ner på sin handled ser han även att skärmen har lyst upp för att fånga hans uppmärksamhet. Han går tillbaka till rummet med roboten för att se vad han behöver göra.

Handledskontrollen ger instruktioner om vad som är kvar att rengöra.

Sam sköljer bort den synliga smuts som finns kvar.

När Sam är klar med grovsköljningen gör han en okulär inspektion för att se så allt ser bra ut. Alla ytor ser rena ut, och det är med andra ord dags för att gå vidare och lägga på skum.

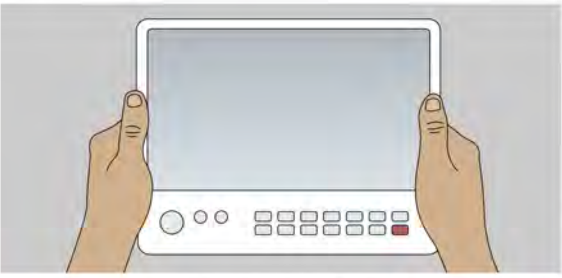


För att gå vidare till nästa steg i städprogrammet bekräftar Sam att grovsköljningen är avslutad. Roboten påbörjar då skumpåläggningen.

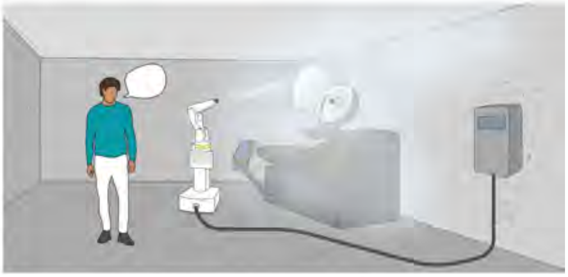
Detachable Device on Robot

Den här fabriken ska rengöras. Här jobbar städaren Sam, och han kommer genomföra arbetet med hjälp av en robot.

Till att börja med måste Sam förbereda rummet genom att plocka bort alla lösa föremål och koppla in roboten till pumpstationen med vatten och kemikalier.

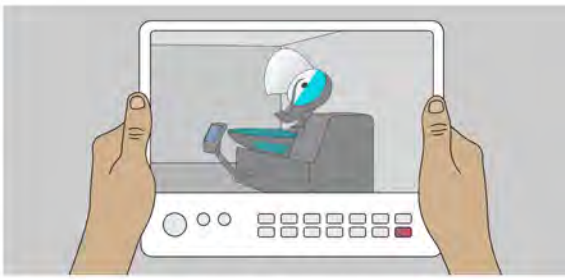


När allt är förberett tar Sam logg enheten från roboten och väljer vilket städprogram som ska köras. Han får då instruktioner för vilka förberedelser som behöver göras innan programmet kan startas. Sam har redan förberett allt, så han bekräftar det och sätter tillbaka enheten på roboten.



Sam använder ett röstkommando för att få roboten att påbörja grovspolningen. Under tiden som den jobbar passar Sam på att gå över till rummet bredvid och skölja av några vagnar.

Efter 30 minuter har roboten spolat av alla ytor som den kommer åt. Det finns dock lite smuts kvar som inte roboten kan hantera, så roboten pausar sitt arbete och signalerar detta. Städaren i rummet brevid hör signalen från roboten går tillbaka till den. När han kommer in i rummet ser han även att robotens ljusmarkering bytt färg. Han går bort till roboten och tar loss enheten för att se vad som ska göras.



Enheten ger instruktioner om vad som är kvar att rengöra.

Sam sätter tillbaka enheten på roboten och sköljer bort den synliga smuts som finns kvar.

När Sam är klar med grovsköljningen gör han en okulär inspektion för att se så allt ser bra ut. Alla ytor ser rena ut, och det är med andra ord dags för att gå vidare och lägga på skum.

För att gå vidare till nästa steg i städprogrammet bekräftar Sam att grovsköljningen är avslutad genom ett röstkommando. Roboten påbörjar då skumpåläggningen.

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Focus Group Questions

As this project was conducted in Sweden, the interviews were held in Swedish.

Questions asked after presenting each concept:

- Vad tycker du spontant om konceptet?
- Hur tror du att det skulle vara att använda en sån här produkt?
- Vad skulle kunna vara bra/dåligt med en sån här lösning?

Questions asked after presenting all concepts:

- Om du jämför alla koncept, vad är bra och vad är dåligt med de olika konceptten?
- Rangordna koncepten och motivera varför