Towards an active predictive relation by reconceptualizing a vacuum robot

A study on the transparency and acceptance of the predictive behaviors of vacuum robot

Master Thesis
Design for Interaction
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TU Delft

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Executive summary

Things are becoming connected, such as electronic consumer products, being able to connect to each other through the Internet, and can interact without human interference (Rowland et al., 2015). By implementing sensors, things can exchange data and combine products to a decentralized system. With the development of Artificial intelligence and Machine learning capabilities, the connected objects are extended with predictive capabilities, and the character of things is changed to "things that predict" (Smit, 2021). If a connected device is able to embrace a predictive system that not only profiles for scripted behavior but could also use the knowledge co-created by all the other similar devices and their users that encounter similar situations, the predictions can be generated based on that. In this case, a new type of interplay between humans and things called "predictive relation" is created.

However, now the relation we have with the connected objects, cannot be the 'background relation' that meets the requirement when the interplay is linking to the future. Challenges such as the transparency and users' acceptance of predictive behavior of the everyday connected product still require us to figure out before the future takes place. It is urged to have an active and valid dialogue to understand the now and the future, and this leads to the question: 'how to design transparent and acceptable predictive relations for the things that predict?' Therefore, to investigate the question, the project will explore the predictive relations and identify the design qualities for predictive relations between humans and things by taking the XiaoMi's Vacuum robot as the starting point of the case study.

This article will start with a brief introduction (Chapter1) of the definition of "Things that predict", explaining the predictive knowledge and relations and leading to the research questions and approaches of this project.

The project will first dive into the investigation (Chapter 2) of the intelligence of the current vacuum robots through the literature review and observation, focusing on robot autonomy, one of the most relevant aspects of robot's intelligence in the field of human-robot interaction (HRI). After deconstructing the intelligence and investigating the interaction of the current vacuum robot, it is observed that 1) The interaction on the APP plays a crucial part and the verbal control or direct interplay with robots is limited. 2) Most of the plan-making and decision-making are highly dependent on humans. 3) The autonomy levels of the current vacuum robot range from manual to full autonomy, but referring to the taxonomy (Beer et al., 2014) developed by Beer's research team, it only occupies 5 of the levels.

After researching the autonomy levels of the tasks and outlining the interaction of the current vacuum robot, the creative sessions (Chapter 3) are conducted to dive deep into the context of the user and the vacuum robot to envision what kind of capabilities can be applied to the vacuum robot as predictive capabilities. The findings and insights from the creative sessions are synthesized into the design qualities in 4 dimensions (Practical, Symbolic, Cognitive, and Social) for the acceptance of predicting vacuum robots. Besides, a wireframe of generating predictive behavior (Chapter 4) is proposed, indicating how a predictive behavior will be triggered and developed in the individual's context and leading to the set up of 2 propositions for transparency and acceptance. The 2 propositions are evaluated (Chapter 5) through the method of 'Wizard-of-oz' and proved valid by combining the results of quantitative and qualitative research.

As one of the results of the evaluation, this project also proposes the idea of "Designer as the facilitator of the human-robot collaboration". The designers can be the ones who help to bring in the background knowledge and the patterns of the predictive relation and indicate the ways for humans and robots to co-perform reliable and meaningful daily practice in their partnership. Eventually, this project takes designing a guidebook (Chapter 6) as one of the ways to clarify the idea and integrates the main results of the project into the guidebook to facilitate the collaboration between humans and predicting robots.

Chapter overview

This chapter introduces the background of this project. It starts with a brief introduction of the Internet of things (IoT), narrowing the scope of this project into the consumer IoT. Follow is the introduction of the definition of “Things that predict”, explaining the predictive knowledge and relations when connected objects are equipped with Artificial intelligence, and able to learn from the networked users in the cloud. Next, the challenges, such as the transparency and acceptance of the predictive knowledge will be discussed and lead to the description of this project’s main research question—— how to design transparent and acceptable predictive relations for the things that predict? The project will explore the predictive relations by taking XiaoMi’s Vacuum robot as the starting point of the case study.

Chapter 1

Introduction

1.1 Internet of things

Things are becoming connected, such as electronic consumer products, being able to connect to each other through the Internet and can interact without human interference (Rowland et al., 2015). By implementing sensors, things can exchange data and combine products to a decentralized system. This system of connected objects is called the Internet of Things (IoT). With the booming of IoT, in the near future, the amount of "things" linked to the Internet will be much larger than the number of "people" and humans may become a minority of data traffic generators and receivers (ITU, 2005). It is obvious that the IoT will influence both the consumer and industrial fields. In industrial environments, the Internet of Things has already made strides in revolutionizing the industry. (World Economic Forum, 2015) On the other hand, the consumer IoT, which is even more relevant to our everyday lives, is changing every aspect of our lifestyle, from the big issues like healthcare and travel to the small wearables on our bodies. In this project, the focus is on the near future of the consumer IoT and their daily interaction with humans.

1.2 Thing that predicts

1.2.1 Predictive knowledge & relations

With the development of Artificial intelligence and Machine learning capabilities, the connected objects are extended with the predictive capabilities and the character of things is changed to “things that predict” (Smit, 2019). If a connected device is able to embrace a predictive system that not only profiles for scripted behavior but could also use the knowledge co-created by all the other similar devices and their users that encounter similar situations, the predictions can be generated based on that. In this case, a new type of interplay between humans and things called "predictive relation" is created.

In Smit’s article (Smit, 2019), he visualizes the hypothesis of the working of predictive relations as follows (Figure 1). Commonly, there will be a feedback loop when users interact with a product or service. According to experiences from the past (t-1), the users will form a mental model (t+1) to understand and foresee what the product will perform. For example, a user considers an object as a cleaning tool based on his/her past experience with the thing and expects it to clean up the floor. When the intelligence is added to the object, like the scripted behavior and algorithm, this scripted profile will also influence the anticipations of the users. Moreover, as a smart object fed with the predictive knowledge generated from the decentralized system, the profile will be formed by the predicted futures and then indirectly shape the user's perception of the product.

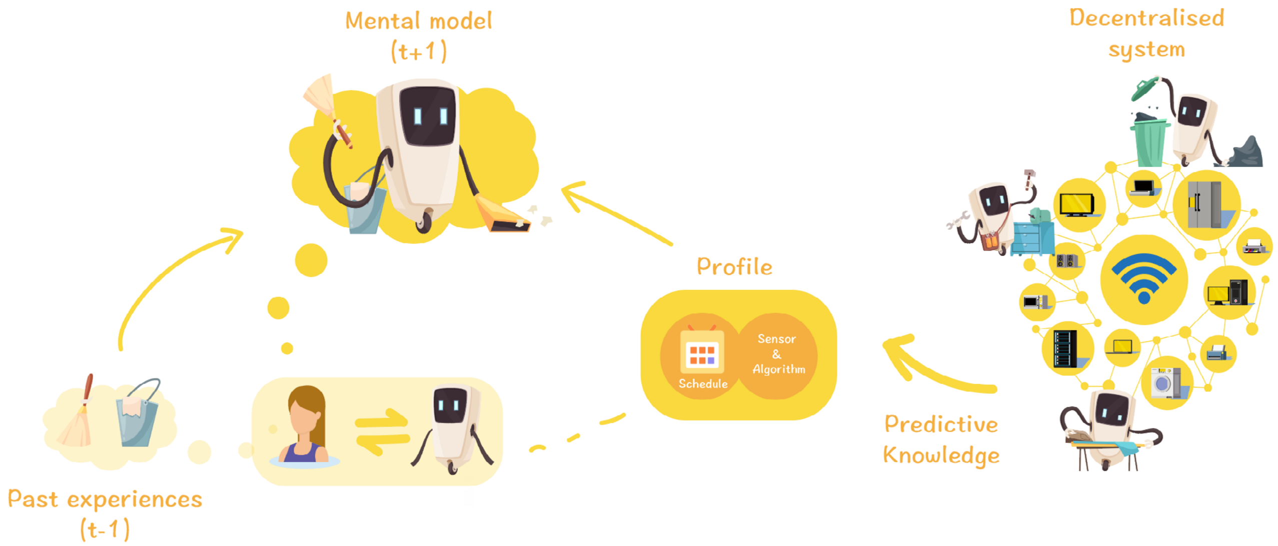


Figure 1: An image of predictive knowledge and relations (Smit, 2019)

1.2.2 Challenges

Transparency

When the robot is able to predict and make decisions autonomously, like a "black box", it's hard to explain why and how it reached certain outcomes. Sometimes the users can immediately realize that the predictions can perfectly meet their needs, while sometimes its predictive knowledge may achieve users' potential demands that they are not yet aware of. Moreover, the predictive knowledge may take over the decision making and the reasons for the predictive decision are sometimes missing, leaving the user with passive use. As a user, you cannot reason it out yourself, knowledge is used that surprises you, but ultimately suits you. To open up the "black box", many have called for creating artificial systems with explainable and transparent qualities that humans can trust (e.g., Wachter et al. 2017; Floridi et al. 2018). Many well-known digital examples such as the suggestions of Google search have already come up with the comprehensive solution on transparency, but cases are few when looking into the IoT products (Smit, 2019).

Acceptance

When we envision how promising a new concept or a new technology can be to enhance our lives, we still reserve the right to decide for ourselves whether to accept this new technology, especially when it will significantly change our existing lives. As everyday objects are implemented with predictive capabilities and become complex systems, one of the possibilities is that we will lose the control that we currently have on the artifacts. At that time, how shall we adapt to this shift in role, or how can robots help us accept them equipped with this new technology? Therefore, a successful implementation of a new technology would not be achieved without the investigation of user acceptance.

1.3 Project Aim

1.3.1 Extending the vacuum robot with predictive capabilities

Vacuum robots can be considered as the poster child for the connected objects in the domestic environment. By collecting and exchanging data with sensors, the vacuum robot is very good at avoiding objects, creating patterns, and returning to its charging point on time. XiaoMi's vacuum robot implements a 3D sensor recognizing the difference between objects such as a toy and the leg of a chair, detecting even small objects on the floor. An object recognition algorithm allows it to identify objects of all kinds and map the safest, most efficient route. Samsung's JetBot 90 AI+ Vacuum robot allows users to connect their smartphone, schedule a cleaning session, set "no-go zones" on a map of their homes, or even connect to the camera to watch the pets while they are away. However, the vacuum robots mentioned above are all integrated with the adaptive system which updates and profiles for scripted behavior. This project will extend the vacuum robot with predictive capabilities based on the understanding of the intelligence of the current robot.

1.3.2 Research goal & questions

Machine learning capabilities and AI power can make things become predictive and create knowledge on possible futures beyond the users' expectations. Now the relation we have with the connected objects, cannot be the 'background relation' that meets the requirement when the interplay is linking to the future. Challenges such as the transparency and users' acceptance of predictive behavior of the everyday connected product still require us to figure out before the future takes place. It is urged to have an active and valid dialogue to understand the now and the future, and this leads to the question: 'how to design transparent and acceptable predictive relations for the things that predict?' Therefore, to investigate the question, the project will explore the predictive relations and identify the design qualities for predictive relations between humans and things by taking the XiaoMi's Vacuum robot as the starting point of the case study.

The following sub research questions are set up for this case study:

1. How does the vacuum robot work in the current situation?

2. What are the possible predictive capabilities of vacuum robots?

3. With the extended predictive capabilities, what qualities make the predicting vacuum robot become acceptable in our life?

1.3.3 Approach

According to the approach for designing predictive relation in Smit's article (Smit,2019), the project will be divided into 3 phases:

Phase 1. Understanding the intelligent behavior of vacuum robot:
Literature review, observation, and interview on the working of vacuum robot

Phase 2. Understanding the context and envisioning the possible predictive capabilities:
a) Researching on the current context with diary booklet to understand the context of current vacuum robot
b) Conducting creative session to envision the possible predictive capabilities and identify the design qualities of predicting vacuum robot

Phase 3. Engaging and evaluating the predictive relations through wizard of oz

Phase 4. Translating the results into a guidebook

Phase 1

Understanding the intelligent behavior of vacuum robot

> Activities

- Literature Review;
- Deconstruct the task of the vacuum robot;
- Identifying the autonomy levels of the tasks;

> Outcomes

- Data flow;
- Service blueprint;
- The autonomy levels of the vacuum robot;

Phase 2

Understanding the context and envisioning the possible predictive capabilities

> Activities

- **Understand the context**
  Diary booklet for context mapping
- **Envision the predictive capabilities & Identify the design qualities**
  Creative sessions

> Outcomes

- Main categories of the predictive capabilities
- Wireframe of the working of the predictive capabilities
- 2 propositions & Design Qualities for Predicting vacuum robot

Phase 3

Engaging and evaluating the predictive relations through wizard of oz

> Activities

- Ideation of the scenarios
- Evaluate the scenarios through wizard of oz

> Outcomes

- The results of the 2 propositions & the modified version of design qualities

Phase 4

Translating the results into a guidebook

> Outcome

- A guidebook for human-robot collaboration

Chapter overview

In the field of human-robot interaction (HRI), to understand the intelligence of smart things, robot autonomy is considered one of the highly relevant aspects to be investigated. Thus, in this chapter, literature review on the definition of robot autonomy and the framework of determining the levels of autonomy will be described. Based on the results of the literature review, 3 aspects of the autonomy —— Sense, Plan and Act, of the current vacuum robot, will be described to outline a general view on the key features. Next, the results of the investigation of the interaction between humans and vacuum robots, and the autonomy levels of the tasks of the current vacuum robot will be visualized and discussed at the end of this chapter.

Chapter 2

Understanding the intelligence of current vacuum robot

2.1 Robot autonomy

Robot autonomy is considered highly relevant to the capability of the smart system to perform its own tasks and actions. In the field of human-robot interaction (HRI), robot autonomy plays a crucial role, since it will influence the performance of the tasks, the way and density of interaction with humans, and the reliability of the performance in an environment. A scientific basis of study on the autonomy of robots can help designers to understand the features and tasks of the smart objects, and identify which actions and tasks should be assigned to humans or robots (Beer et al., 2014). Thus, to understand the intelligence of a smart object——a vacuum cleaner as an example, researching its autonomy is important.

2.1.1 Definition of Robot autonomy

Over the years, the studies of the definition of robot autonomy have been discussed from the perspective of psychology and engineering (Franklin & Graesser, 1996, p. 25; Murphy, 2000, p. 4; Thrun, 2004, p. 14). The term is applied to characterize varied aspects of robotics, from the ability of the robot to manage itself to the level of required human intervention. In Beer's study, they proposed a more detailed definition, which integrates current generally accepted definitions of autonomy and indicates common characteristics of autonomy (i.e, sense, plan, act, task-specific goal, and control):

This definition helps deconstruct the behavior of an autonomous robot and indicates that the characteristics should be taken into account when researching robot autonomy. Therefore, as discuss later in this report, the project will start analyzing the autonomy of the current vacuum robot by deconstructing its task in 3 dimensions: Sense, Plan, and Act.

2.1.2 Levels of robot autonomy (LORA)

Views on how autonomy impacts human-robot interaction are different. In the case of Huang's research team, they hold the view that the level of robot autonomy (LORA) has a negative linear relationship with the frequency of HRI, which means that the higher LORA, the lower the frequency of HRI (Huang et al., 2004). The LORA also reveals that autonomy is not a binary allocation: either human or robot is allocated to a specific goal and action, but a continuous category that splits between the human and robot, indicating the degree of dynamic control of the tasks. Beer's team (Beer et al., 2014) highlights that the robot's autonomy is in a state of fluctuation, which may switch between levels over time according to the interaction, task, and environment. Due to the variety and fluctuating state of autonomy levels, it is important for the researcher and designer to understand and identify a smart robot with a proper autonomy level as well as classify the elements that will affect and be affected by the autonomy. Thus, a review of a guideline or a framework of LORA is required before studying the autonomy and the intelligence of a smart robot.

> "**The extent to which a robot can sense its environment, plan based on that environment, and act upon that environment with the intent of reaching some task-specific goal (either given to or created by the robot) without external control.**" **(Beer et al., 2014)**

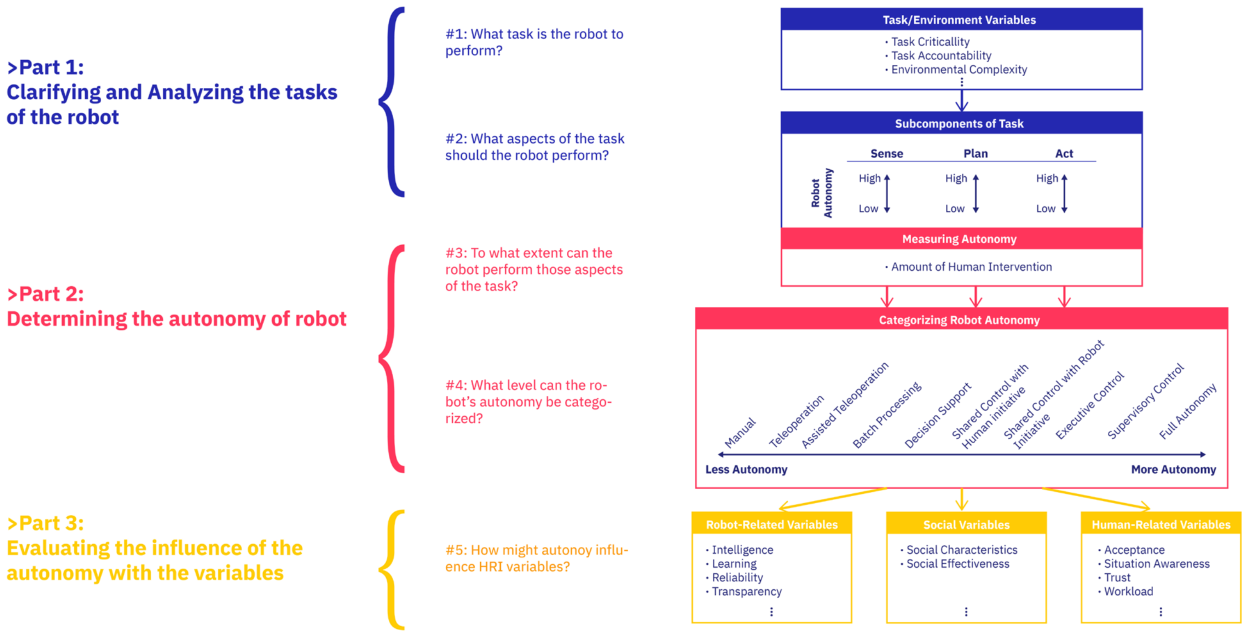


Figure 2: Guideline and Framework: Levels of Robot Autonomy (Beer et al., 2014)

2.1.3 Guideline and Framework: Levels of Robot Autonomy (LORA) in Human-Robot Interaction

Levels of Robot Autonomy (LORA) range from manual to full autonomy. To identify the process of determining LORA and categorize LORA, Beer's team propose a framework of LORA (Beer et al., 2014) (Figure 2) The framework consists of 3 consecutive parts:

1) Clarifying and Analyzing the tasks of the robot

First, the robot designer should clarify the robot's capabilities by answering the question: "What task is the robot to perform?". Meanwhile, the specific demands of the task should also be taken into account before determining the autonomy, such as task criticality, task accountability and the complexity of the environment. After the tasks of the robot are clarified, the robot designer should consider the subcomponents of the tasks, and identify to what degree the robot can carry out each subcomponent by allocating it between human and robot. A task, no matter how easy or complicated, could be divided into 3 subcomponents: Sense, Plan and Act. And the allocation of each subcomponent, either human or robot, can be different and influence the result of determining the autonomy (Murphy, 2000; Rosen & Nilsson, 1966).

2) Determining the autonomy of robot

In Beer's framework, they also propose a qualitative taxonomy to categorize the autonomy of robots. (see in Appendix E) The taxonomy provides a description of each autonomy level and indicates the suggested autonomy level for a different allocation of the task subcomponents. So, based on the results of allocating the subcomponents in part 1, designers and researchers are able to determine the LORA via the taxonomy.

3) Evaluating the influence of the autonomy with the variables

Once the LORA is determined, there is a need for evaluating the robot's autonomy level is appropriate for the HRI in the context. So, Beer also provides some criteria and variables, such as Robot-Related Variables, Social Variables and Human-Related Variables for designers to evaluate the influence of autonomy. But they also stress that these are not exhaustive and will be changed via different situations.

In conclusion, to understand the intelligence of the current vacuum robot, the research will start from deconstructing the autonomy of the vacuum robot, observing the main tasks and interaction between human and vacuum robot via data flow and then identify the autonomy level of each current task based on Beer's framework.

2.2 Deconstructing the intelligence of the vacuum robot with the definition of autonomy

"A robot's capability to sense, plan, and act within its environment is what determines its autonomy. "

(Beer et al., 2014)

2.2.1 Sense

By implementing the sensors, the robots are given the power of sensing the world and finding out cues to understand their partners——human beings. To investigate the sensing capabilities of vacuum robots, observation and reviewing the product manual of Xiaomi's vacuum robot are conducted. As Figure 3 shows, 11 different sensors are implemented in Xiaomi's vacuum robot to enable the robot to sense varied objects. Among these 11 sensors, some are aimed at detecting the external environment of the robot, for example, Wall Sensor and Cliff Sensor are used to identify wall and cliff respectively to prevent the robot from collision and fall, while some are intended to identify the internal status of the robot, for example, Dust Box Detector is used to identify if dust box is in the the robot, so as to help the robot determine whether it can carry out cleaning work. According to the above 2 aims of the sensors, the vacuum robot's capabilities of sensing are categorized as object recognition and robot status recognition (Figure 3).

Sensor	Objects being sensed	Aim of sensing
Laser Distance Sensor (LDS)	Distance	Object recognition
Wall Sensor	Wall	
Cliff Sensor & Anti-drop Sensor	Cliff	
Visual Sensor	Identify objects. eg. doors and chair legs	
Collision Sensor	Collision	
Dust Box Detector	Dust Box	Robot status recognition
E-Compass	Direction	
Accelerometer	Acceleration	
Odometer	Mileage	
Fan speed Sensor	The speed of the fan	

Figure 3: The overview of the sensors of Xiaomi vacuum robot

As the Figure 3 shows, the sensors of current vacuum robots are largely occupied with the aims of recognizing objects and robot status. However, when considering human and robot interaction, the robot's ability to understand human intention is also important since it enables the robot to provide appropriate services to humans (Blakemore & Decety, 2001). Yu indicates that the key technology of human intention understanding is not only the robot's ability to recognize the object, but also the ability to sense and classify human action as well as to link the relationship between things and human actions (Yu et al., 2015). Thus, the robots' capability of sensing human action can also be taken into consideration when designing a predicting robot that performs proper and suitable predictions.

2.2.2 Plan

Commonly, the algorithms guide the autonomy of smart devices, which enable the robots to analyze the information grasped by their sensors and to plan for their actions based on their understanding. Take Xiaomi's vacuum robot as an example, the typical capabilities of planning are as follow:

Cleaning Algorithms

The ability of path planning is a crucial element of vacuum robots since it will influence the efficiency of their basic job —— self-driven cleaning. When the robot starts cleaning, the robot carries out its intellectual scheme of scanning. As Figure 4 shows, first, the device walks along the walls and separates the space into areas, and then fills up the zones with an "S " shape cleaning route. When the cleaner has completed cleaning one area, it moves to the next with no gaps. The robot will automatically return to the recharge base when the work is done.

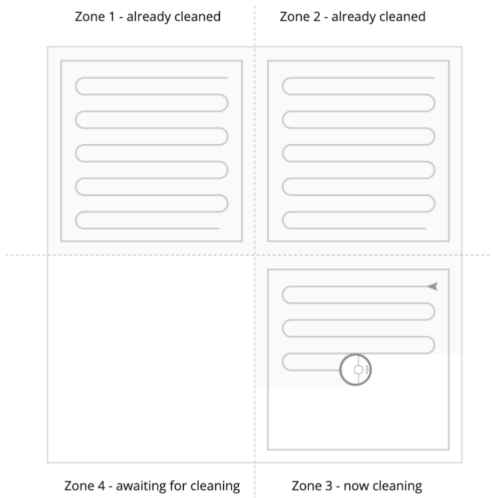


Figure 4: The cleaning algorithms of current vacuum robot

Spot Cleaning Mode

The map detected by the robot can be divided and merged into virtual small zones. The spot cleaning mode can specify the cleaning intensity and frequency for each zone, and set up the cleaning order of the room. Through a few setups from the user, a unique cleaning plan can be generated.

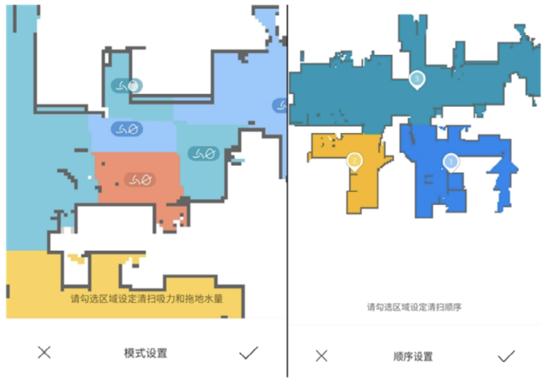


Figure 5: Example of Spot Cleaning Mode of Xiaomi's vacuum robot

Smart scenes

Smart Scenes are the features that are set up by the users with simple conditional statements to trigger specific actions of vacuum robots. Besides, through smart scenes, Xiaomi's vacuum robot can be linked with other smart home devices. For example, in Figure 6, the user can set up the conditions that if he/she says "I will go out for a while" to the smart speaker, the smart devices will automatically perform actions such as turning on the vacuum robot and turning off the lights.

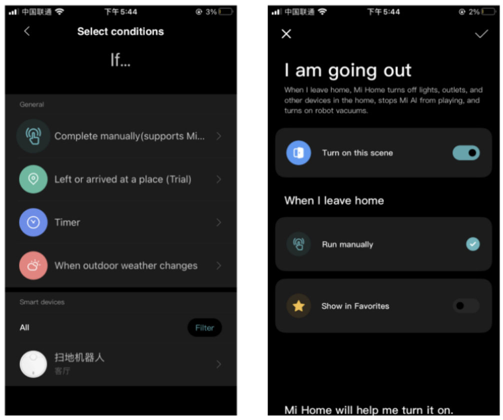


Figure 6: Example of Smart Scenes of Xiaomi's vacuum robot

To sum up, despite the capability to navigate and plan for an optimal path, the abilities of the vacuum robot to plan its behavior based on the scenario, i.e, in what conditions to perform and how to perform appropriate actions, are highly dependent on the scripted algorithms set by the programmer and the commands from the user. This will be also discussed in detail in Session 2.3.1.

2.2.3 Act

To investigate how the vacuum robot can perform the tasks, a scan of the vacuum robot's basic action is conducted and listed as follows (Figure 7).

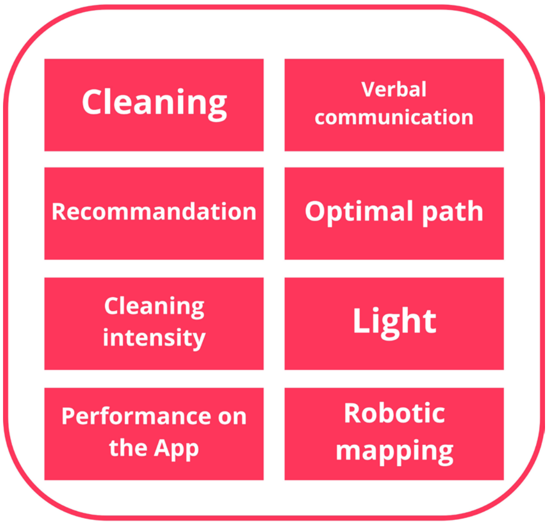


Figure 7: Table of vacuum robot's basic actions

The main action of the vacuum robot is to clean. Besides, the robot is able to clean in varied intensity from strong to weak. When the robot is cleaning the floor, it moves towards the target spots with optimal paths and scans the environment in order to deliver the map of the room to the App. Through the App, the vacuum robot is able to show its performance and to receive commands from the user. It is worth mentioning that the ability to recommend certain smart scenes is implemented in Xiaomi's system, such as recommending a new action of the vacuum robot when a new smart device is connected to the smart home system. However, the recommendation is only generated from the App based on the new connections between smart devices and App, which means that the current vacuum robot is not capable of generating suggestions based on what it experiences in the user's context.

Moreover, the other basic actions like verbal and light communication allow the robot to physically report its current status and actions to humans. These listed basic actions, in different combinations, constitute the ability of the vacuum robot to perform a variety of cleaning tasks.

2.2.4 Conclusion

In conclusion, above all give a general view on the key features and the intelligence of the current vacuum robot from 3 dimensions of autonomy——Sense, Plan, Act. In the dimension of sense, the capability of the robot to perceive human intention is one of the most essential aspects of the interaction between humans and robots. To do so, the robot's ability to collect data from the human side, such as the data of human actions, is one of the key technologies of understanding humans (Yu et al., 2015). However, all the sensors of the current vacuum robot are mainly to help the robot recognize the object in the environment and detect its own status. So it creates the possibility to extend it with the ability to sense human action when designing a vacuum robot that predicts the services that suit humans' needs. Besides, the abilities of the vacuum robot to plan its behavior are highly dependent on the preset algorithms and the command from the human. Also, the ability to perform the tasks is the combination of the basic actions.

After having an overview of the vacuum robot's key features, there is a need to have further research on the interaction between humans and robots in order to figure out 1) what tasks do the vacuum robots carry out in our daily life, 2) how do vacuum robots interact with humans, 3) how does the data exchange between vacuum robots and users. These will be discussed in the next session.

Besides, to dive deep into the autonomy of vacuum robot, the research on the LORA of vacuum robot will be conducted in Session 2.4, focusing on 5) to what extend the robot can perform the 3 subcomponents of each task——Sense, Plan, and Act, 6) what is the autonomy level for each task.

2.3 The interaction between humans and vacuum robots

2.3.1 Main tasks of the vacuum robot

To study the interaction between humans and vacuum robots, the priority is to figure out and classify the daily activities and tasks within this interplay. The tasks are described from the human perspective and clustered as 1) preparing for the cleaning, 2) Opportunistic cleaning, 3) Planned cleaning, 4) Solve the problems when cleaning, 5) After cleaning.

Preparing for the cleaning

Usually, before the robot is able to clean, some components, such as an empty dust box, brushes, should be installed. Sometimes, users must preclean up the cables scattered on the ground to prevent robot stucking and overturn. Through the App, users may receive suggested Smart Scenes (introduced in Session 2.2.2) of the vacuum robot based on the smart devices that are connected to the App. Also, if needed, customizing the cleaning intensity and the reporting voice of the robot should be finished before cleaning.

Opportunistic cleaning

Opportunistic cleaning is the type of cleaning task that is temporary and unscheduled (Forlizzi & DiSalvo, 2006). Sometimes the users and vacuum robots may need to carry out some unexpected and pressing cleaning tasks, such as cleaning up specific areas and rooms that are covered by scattered nuts with spot cleaning and room cleaning mode. Also, to clean up some corners of the walls may need humans to manually teleoperate the vacuum robot.

Planned cleaning

The cleaning activities that are regularly carried out, such as weekly scheduled cleaning, cleaning in the condition of leaving home, are categorized as planned cleaning (Forlizzi & DiSalvo, 2006). Also, users can set up a plan that, within a range of time, the robot cannot operate any task and reduce the flashing frequency of the lights.

Solve the problems when cleaning

The robot may encounter problems in the cleaning route. Solving problems, such as getting rid of stucking and going to charge when there is a lack of power in the midway, are common activities of cleaning routine.

After cleaning

When the cleaning is complete, the robot will automatically go to the charging base and switch to the Sleep Mode if the robot does not operate for more than 10 seconds. Also, to maintain the robot and obtain new features, users are required to replace the consumables and update the system regularly.

Figure 8: Map of main tasks of vacuum robot

2.3.2 Data flow between human and vacuum robot

To analyze the interaction, the map (Figure 9) visualizes how the commands from the users can be delivered to the vacuum robots and how the generated data from the robot's algorithm and other smart devices in the home system pass to the humans. The blue arrows are the flow of data from the user to the robot, while the red arrows are the opposite. Generally, in the frontstage, the users create data and pass it to the App or the smart speaker to control the robot. And then, the vacuum robots carry out the goals with their background action, such as navigating by the algorithms and the information provided by the other smart devices. In return, the robots report their status and actions in the frontstage.

2.3.3 Conclusion

In the data flow chart, most of the data arrows from the user (yellow arrows) are indirectly passed to the robot through the App or smart speaker. The interaction on the APP occupies most of the interplay between humans and vacuum robots. Although the ability of verbal communication is implemented in the current vacuum robots, the communication is unidirectional, which only allows the robot to report its status verbally. And if the user wants to control the vacuum robot with his/her verbal command, he/she has to talk to the smart speaker and then the smart speaker controls the vacuum robot. Thus, the direct interaction with current vacuum robots is limited.

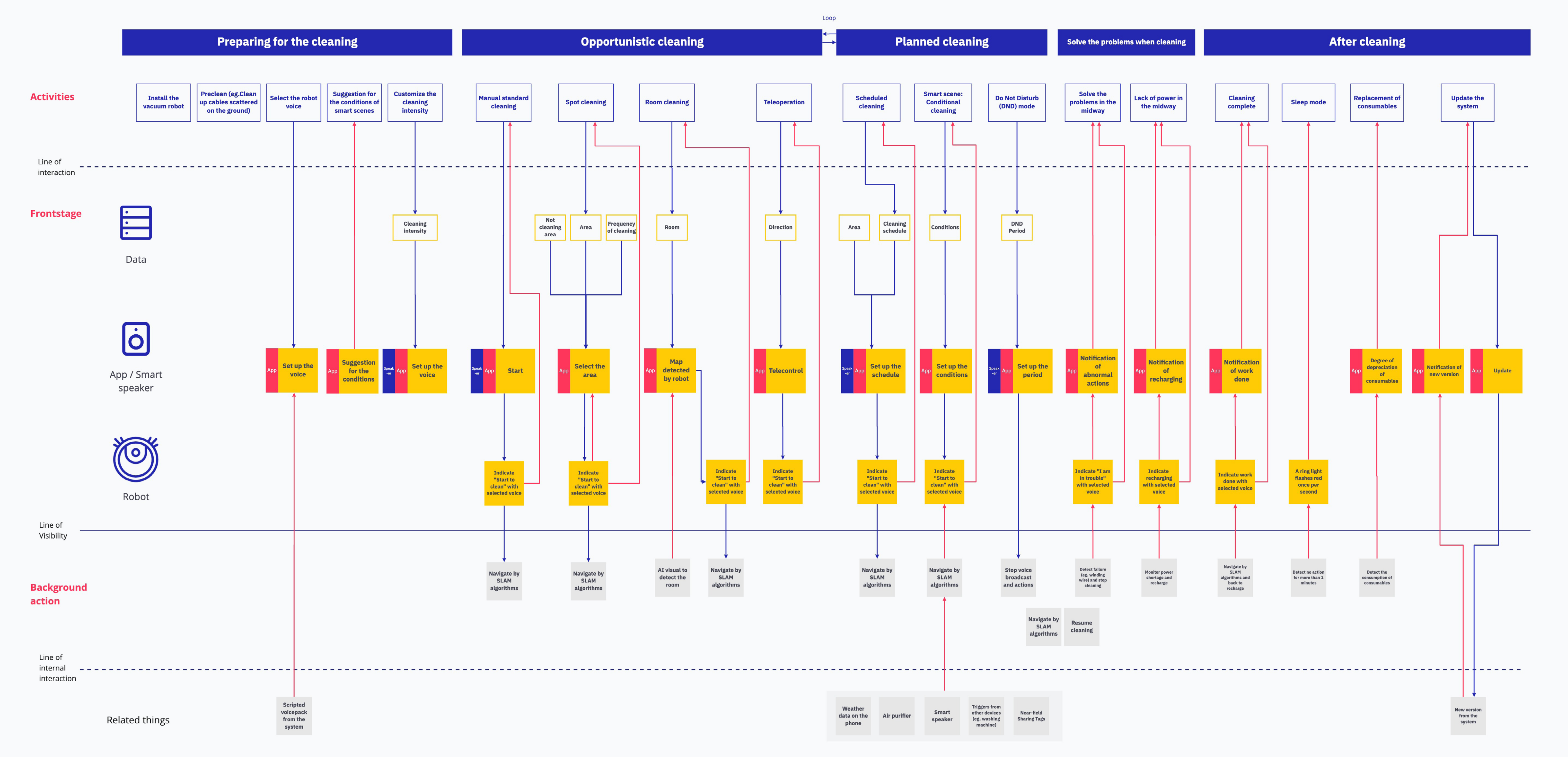


Figure 9: The maps of the data flows of the current vacuum robot

Figure 9: The maps of the data flows of the current vacuum robot

2.4 The autonomy level of the current vacuum robot's tasks

2.4.1 Analyzing the tasks of the current vacuum robot

In Session 2.3.1, when classifying the main tasks of the vacuum robot, it's easy to be realized that some tasks are mainly dependent on humans, some can be self-driven by robots, or some need to co-perform by humans and robots. In Beer's framework, each subcomponent of the tasks——sense, plan, and act can be allocated to the human or the robot or both. Thus, a study of analyzing the allocation of the subcomponents of each task is conducted before determining the LORA and shown as folow (Figure 10).

From the chart, the capabilities of planning in most tasks highly depend on humans, which means that users take most of the responsibility for decision-making and plan-making in their cleaning routine.

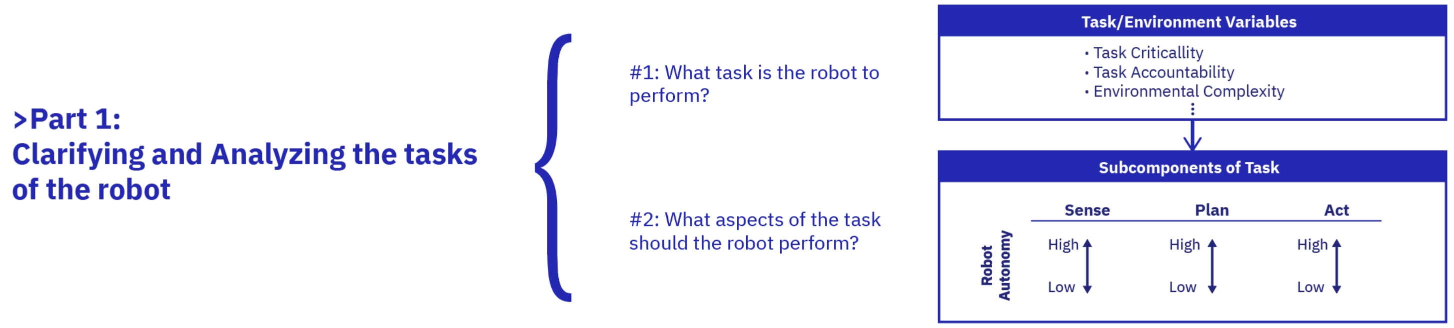


Figure 11: The part 1 of the framework of determining the autonomy levels with part

Loop

Subcomponent of the task — H: Human   R: Robot

Activities	Preparing for the cleaning: Install the vacuum robot	Preclean (eg.Clean up cables scattered on the ground)	Select the robot voice	Suggestion for the conditions of smart scenes	Customize the cleaning intensity	Opportunistic cleaning: Manual standard cleaning	Spot cleaning	Room cleaning	Teleoperation
Sense	H	H	H	H/R	H	H	H/R	H/R	H/R
Plan	H	H	H	H	H	H	H/R	H/R	H/R
Act	H	H	H	H	H	H	R	H/R	R

Activities	Planned cleaning: Scheduled cleaning	Smart scene: Conditional cleaning	Do Not Disturb (DND) mode	Solve the problems when cleaning: Solve the problems in the midway	Lack of power in the midway	After cleaning: Cleaning complete	Sleep mode	Replacement of consumables	Update the system
Sense	H/R	R	H/R	R	R	R	R	R	R
Plan	H/R	H/R	R	H	R	R	R	H	H
Act	R	R	R	H	R	R	R	H	H

Figure 10: The maps of the subcomponents of the taks of the current vacuum robot

Figure 10: The maps of the subcomponents of the taks of the current vacuum robot

Figure 12: The maps of the autonomy levels of the taks of the current vacuum robot

2.4.2 Identifying the autonomy level of the current vacuum robot

A scientific basis of study on the autonomy of robots can help designers to understand the features and tasks of the smart objects, and identify which actions and tasks should be assigned to humans or robots (Beer et al., 2014). Referring to the taxonomy developed by Beer's research team, the allocations of the subcomponents can also reveal the robot's autonomy level of each task (Figure 12). For example, if the subcomponents of one task are all allocated in the human side, checking from the taconomy (see in Appendix E), the autonomy level of this task is determined as fully manual. The autonomy levels of the current vacuum robot range from manual to full autonomy. In the stage of Preparing for cleaning, the vacuum robot is at the lowest autonomy level, depending highly on the human. On the contrary, in the stage of Planned cleaning and After cleaning, the robot carries out most of the tasks with high levels of autonomy. Moreover, the vacuum robot does not perform all the autonomy levels indicated in the taxonomy since many of the dots in the chart are in the same levels and occupying only 5 autonomy levels. The 5 autonomy levels are:

1) Manual
The human carries out all aspects of the task including sensing the environment, generating plans, and performing actions.

2) Batch Processing
The environment is monitored and sensed by both the human and robot. However, the human sets the goal and plan of the task. The robot then performs the task.

3) Decision Support
The environment is monitored and sensed by both the human and robot. However, different from Batch Processing, the robot provides the choices of plans and actions for the human to choose

4) Supervisory Control
The robot performs all aspects of the task, but the human continuously monitors the robot and sets a new goal and plan. If the robot encounters difficulty, it can prompt the human for assistance

5) Full autonomy
The robot performs all aspects of the task without human intervention, generates new goals and plans, and then implements them by itself.

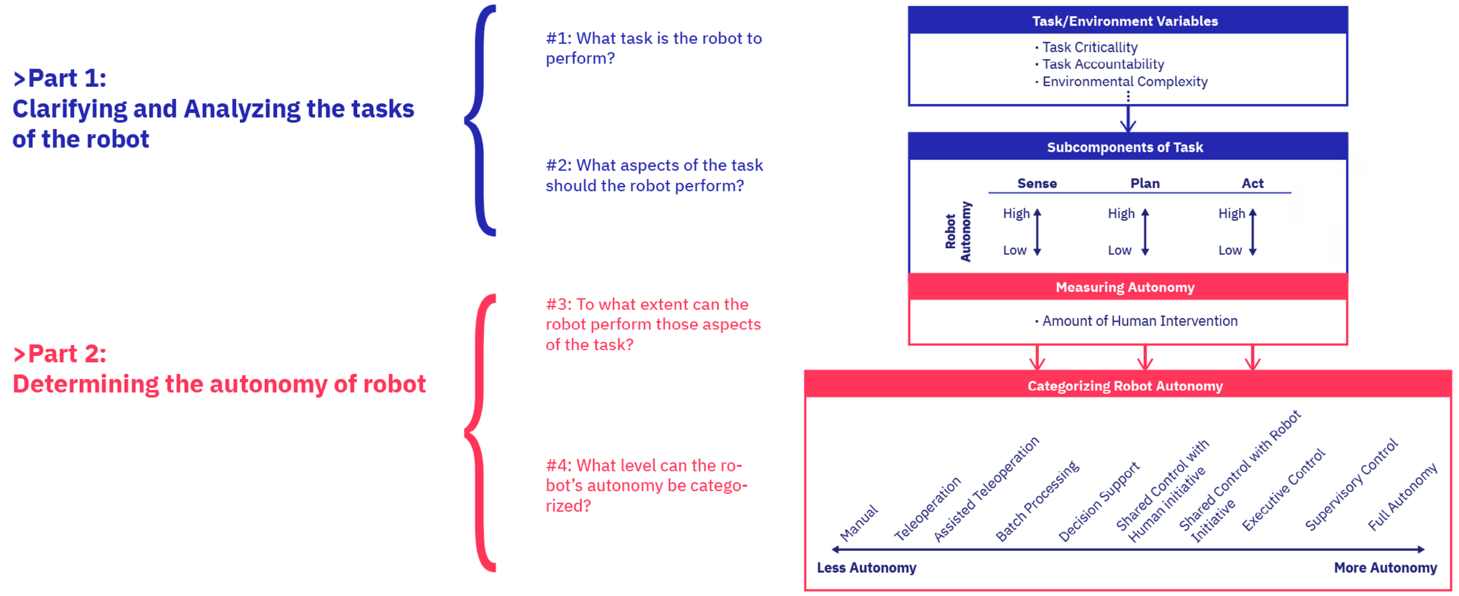


Figure 13: The part 1 & part 2 of the framework of determining the autonomy levels with part

Key takeaways of Chapter 2

- **The interaction on the APP plays a crucial part. Verbal control or direct interplay with robot are limited**

  The interaction on the APP occupies most of the interplay between humans and vacuum robots. Although the ability of verbal communication is implemented in the current vacuum robots, the communication is unidirectional, which only allows the robot to report its status verbally. And if the user wants to control the vacuum robot with his/her verbal command, he/she has to talk to the smart speaker and then the smart speaker controls the vacuum robot.

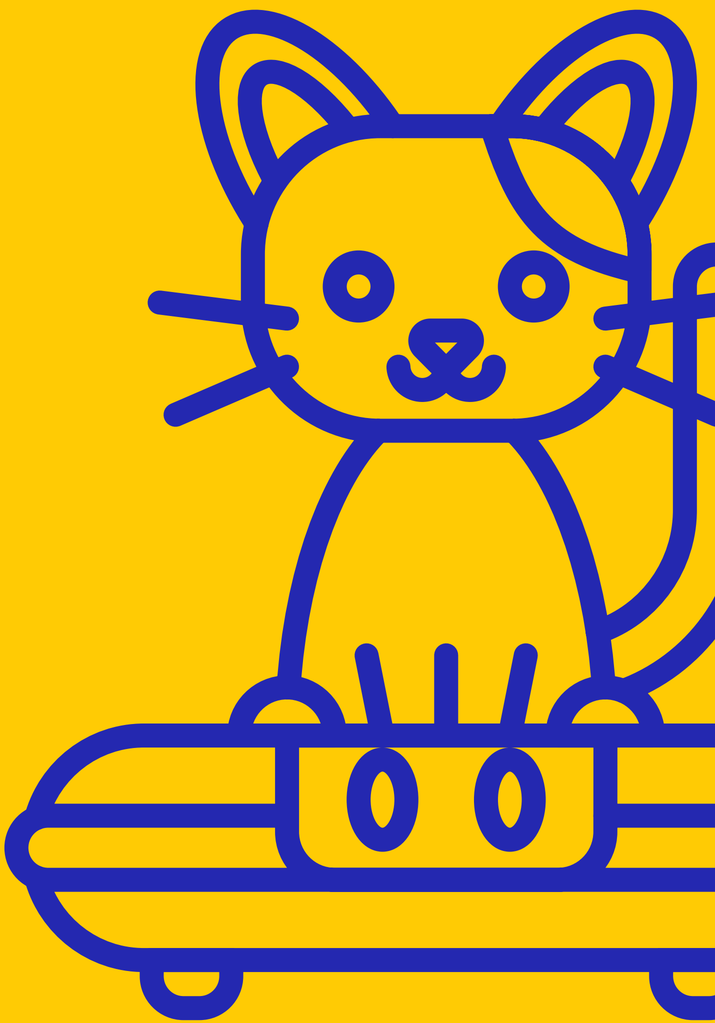
- **Most of the plan-making and decision-making are highly dependent on humans.**

  Despite the capability to navigate and plan for an optimal path, the abilities of the vacuum robot to plan its behavior based on the scenario, i.e, in what conditions to perform and how to perform appropriate actions, are highly dependent on the scripted algorithms set by the programmer and the commands from the user.

- **The autonomy levels of the current vacuum robot range from manual to full autonomy, but only occupies 5 of the levels referring to the taxonomy (Beer et al., 2014).**

  The vacuum robot does not perform all the autonomy levels indicated in the taxonomy since many of the dots in the chart (Figure 12) are in the same levels and occupying only 5 autonomy levels. The 5 occupied are: 1) Manual, 2) Batch Processing, 3) Decision Support, 4) Supervisory Control, 5) Full autonomy. These 5 autonomy levels will serve as the sope of the prototyping in the Chapter 4.

Chapter overview



After researching the autonomy levels of the tasks and outlining the interaction of the current vacuum robot, the next step is to dive deep into the context of the user and the vacuum robot to envision what kind of capabilities can be applied to the vacuum robot as predictive capabilities. Thus, the description of the process of the creative session will be presented in this chapter. And then, the Domestication Theory (Søraa et al., 2021; Berker, 2005; Lie and Sørensen, 1996), this project synthesizing the findings and insights from the creative sessions into the design qualities for the acceptance of predicting vacuum robots.

Chapter 3

Understanding the context & find out the possibilities of predictive capabilities

3.1 Overview of the study for possible predictive knowledge of vacuum robot

In Chapter 2, the research on the autonomy levels of the tasks and the data flow provides an overview of the intelligence of the current vacuum robot. According to the approach for designing predictive relations (Smit, 2020), the next step is to dive deep into the context of the user and the vacuum robot to envision what kind of capabilities can be applied to the vacuum robot as predictive capabilities. Besides, this project will also research the qualities that can help the predicting vacuum robots perform appropriately and integrate into our lives. In conclusion, 2 research questions for the qualitative study are set up as follow:

1. What predictive capabilities could be applied to the vacuum robot in the future?

2. What qualities can help the predicting vacuum robots become acceptable in our life?

The study consists of 3 parts and was conducted through the miro board (an online collaborative tool) (Figure 14). In the first part, the participants will be provided with a 4-day diary template to help them record their daily individual practices of cleaning and their relationship with the current vacuum robot. After that, they will be asked to bring their dairy booklets together to present and discuss their experience with vacuum robots. Meanwhile, experts from the field of robotics and design will join the discussion and the participants will be sensitized and inspired by the experience from each other. In the final part, a 1-hour creative session will be conducted through sketching and discussion to envision the predictive capabilities of vacuum robots and their impacts.

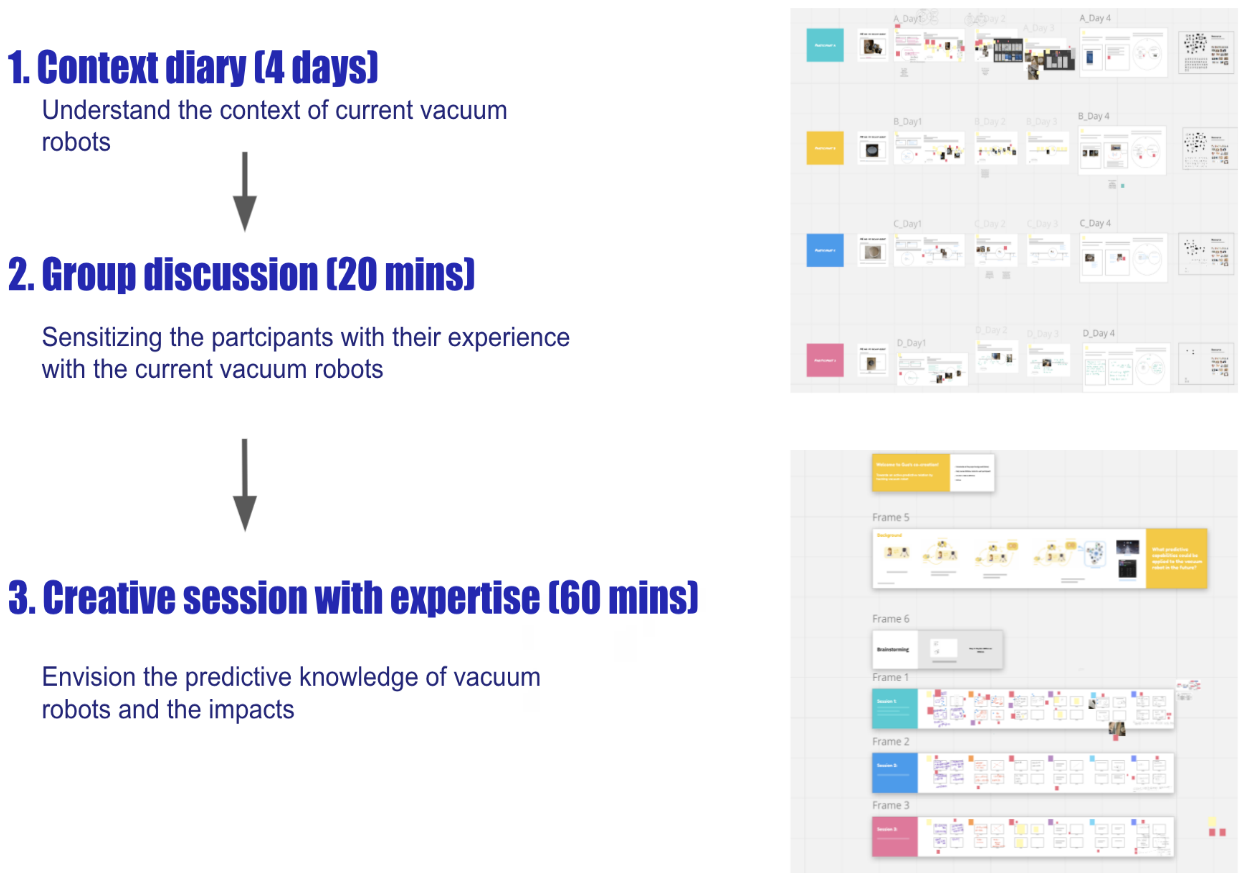


Figure 14: An overview of the study

3.1.1 Theory foundation of the study

Sensitizing the expression of participants: Path of expression

To help the participants envision the predictive knowledge of vacuum robots in the future, the study follows the path of expression (Sanders,2001) ——ask about the present and the past before asking about the future (Figure 15). It enables people to connect to what their concerns are from their past and present experiences and use that to trigger their feelings and ideas about the future. Thus, the study starts by recording participants' experiences and feelings about the present and past through the dairy booklets and then discusses the future scenarios of predictive behavior of vacuum robots in the creative session. In addition, the diary booklet as a sensitizing tool, it also follows the path of expression to help the participant record and present their personal experience on the booklet. It not only asks about participants' current and past experience but also requires them to think about the vacuum robots' possible connections with other objects in the future, which serve as a warm-up of the creative session (Figure 16). The detailed diary booklets can be found in Appendix A.

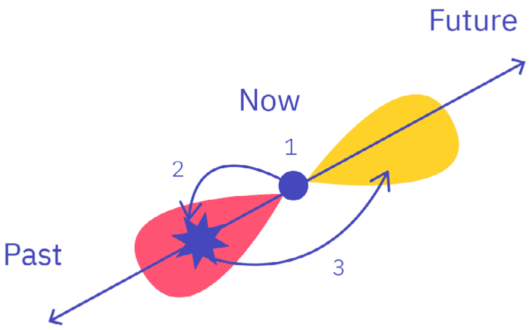


Figure 15: The path of expression (Sanders,2001)

Sensitizing the findings: Domestication theory

To answer the research question: what qualities can help the predicting vacuum robots perform appropriately and become acceptable in our life, the Domestication Theory (Søraa et al., 2021; Berker, 2005; Lie and Sørensen, 1996) is applied to lead the questions during the creative session and sensitize the findings after the study. Apart from the theory such as Technology Acceptance Model (TAM) (Davis, 1989) focusing on the measurable factors of a concrete and realized system like, perceived easy-of-use, the Domestication Theory uses the metaphor of taming a wild animal into the home enviornment to investigate how a new technology is being integrated and adopted in users daily life. Thus, the acceptance qualities of an immeasurable and unrealized technology such as things become predictive, are more easier to be investigated through the Domestication Theory. The Domestication Theory provides a model which is divided into 4 dimensions: 1) Practical domestication, 2) Symbolic domestication, 3) Cognitive domestication, and 4) Social domestication (Søraa et al., 2021; Berker, 2005; Lie and Sørensen, 1996).

Practical domestication: This dimension points out the interactions that are physical and observable with the technology. This can refer to how the technology can be used, such as a button on the product to push.

Symbolic domestication: This refers to what the technology means for the users after having it in their life, illustrating the unobserved after-effects of adopting the technology.

Cognitive domestication: are the mental practices associated with the use of technology, eg., how the users learn from and through the technology and how the technology changes the users in return.

Social domestication: refers to how technology is influenced not only by individuals but also through a diversity of actors who hold agency in how the technology is applied to the lives of users and others around them.

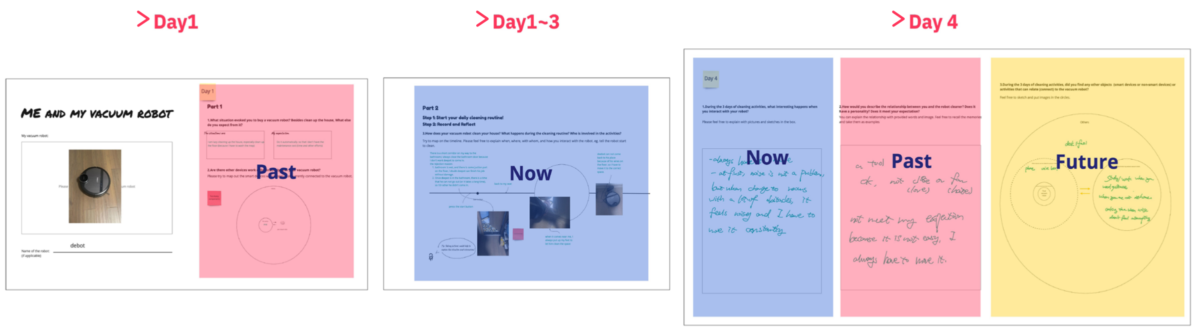


Figure 16: An example of the diary booklet

Figure 17: The process of analyzing the design qualities

Søraa also states that the dimensional model of domestication reveals the process of adopting new technology is not a linear pathway, but all the dimensions influence each other at the same time. (Søraa et al., 2021)

This project will use the domestication theory to first find out the qualities that make the current vacuum robot be adopted in our life. And then these will serve as the basis for identifying the qualities of predicting robots after the creative session (Figure 17).

3.2 Context diary & Group discussion——Understanding the context of the current vacuum robot

3.2.1 Objectives

1) Understanding the context of current vacuum robot;

2) Finding out the qualities that make the current vacuum robot acceptable in our life;

3) Sensitizing participant to envision the predictive capabilities in the future;

Structure

In this part, the dairy templates will be provided to the interviewees through the Miro board, to help them record their daily interaction with the vacuum robot. The dairy consists of 4 days of exercise. To finish the exercise, it will take approximately 15 mins each day. The dairy will be served as inspiration and presented in the group discussion.

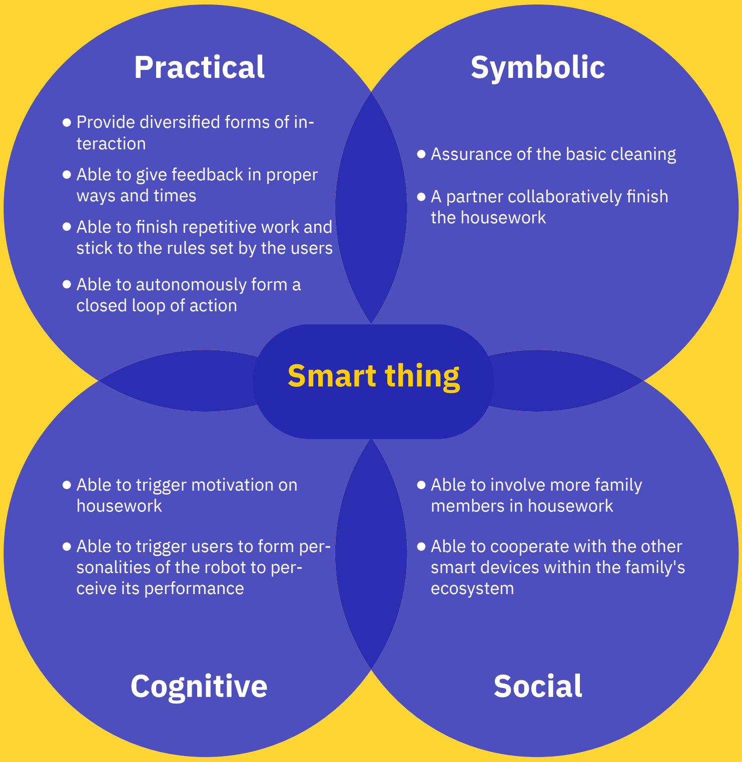
1. Introduction of the dairy
2. Sign up for the consent form
3. Finish the dairy
4. Group discussion (20 mins)

3.2.2 Method

Participants

4 participants from TUDelft with design background are invited to finish the diary booklets. In addition, they both own a vacuum robot and have the experience of daily cleaning practices with the vacuum robot.

What qualities make SMART THING (Current vacuum robot) become acceptable in our life?



3.2.3 Findings: Domestication qualities of current vacuum robot

The results were interpreted and categorized into 4 dimensions according to the domestication theory from the raw data in the transcript of the creation session. (see in the Appendix C&D)

Practical domestication

1) Provide diversified forms of interaction

One of the important reasons that enable a vacuum robot to be accepted and employed by the whole family is the robot's ability to provide multiple forms of interaction. Different forms of interaction also meet various needs and accommodate the diverse competence of family members of different ages to use the technology. One participant mentioned that she was a member of a large family with three generations living under one roof. Her brother is a geek of smart devices who introduced the vacuum robot to the family. So he plays the role of administrator, controlling the family's smart devices through the app, including the vacuum robot. Her little sister and grandfather, on the other hand, usually physically interact with the robot because of the limitations of their ability to use the phone, such as commanding the robot through talking to the smart speaker and learning about the robot's status through the robot's voice broadcast.

P1: "My brother controls the app, as the administrator of all smart devices in the family. My little sister likes to chase and play with the robot. Sometimes, my grandpa will directly yield to the smart speaker to stop the robot when he is taking a nap."

Figure 18: The vacuum robot is teaching the little sister how to take out the dust box with voice

2) Able to give feedback in proper ways and times

Reasonable and appropriate feedback can help users understand how the robot is working and thus build up trust. But if the feedback is too detailed, unnecessary, and frequent, it can be counterproductive. In the interviews, one participant complained that sometimes the feedback from the robot was annoying. One day, the participant's phone was bombarded with messages that only prompted the need to replace a consumable part that did not affect the robot's normal working.

P1:"...BUT you know how many messages it sent to me this morning?? When I checked them, it just turned out that it wanted me to replace the bush. But if I don't do that, it does not affect its normal work!"

Besides, we usually associate the feedback from the machine with various message prompts, such as beeps and pop-ups on the app. However, in fact, users do not only get feedback through the information alerts. Some participants, on the other hand, considered the noise generated by the robot as the feedback for the proper working of the robot.

P3:"(...) sometimes, the noise of vacuum robot makes me feel at ease because it lets me know that he is working normally and it makes me feel confident to let it work by himself"

Thus, for robots and humans to coexist in a sustainable way, it is an important quality for robots to be able to provide corresponding forms of feedback according to different situations.

3) Able to finish repetitive work and stick to the rules set by the users

3 participants valued the current vacuum robot's ability to finish the tasks which the user can't do or would be more difficult for the humans to perform than the robots. Specifically, it is the task that is mechanically repetitive and would be often painful for humans to finish punctually and constantly, but robots are able to perfectly fulfill them without complaints. In addition, sweeping, such as the floor under the table and the area under the bed, is often difficult for humans to tackle with a broom. However, vacuum robots can also get through these difficulties much more easily than humans.

4) Able to autonomously form a closed loop of action

The robot's ability to start sweeping, plan its route, complete sweeping and return to charging forms a closed loop of action. This loop enables the robot to perform a complete cleaning practice one after another without human intervention.

P3: "I think one of the smartest aspects of the current robot is that it can automatically return to recharge after completing the cleaning task so that I don't need to have additional input to the robot and it will be ready for the next time."

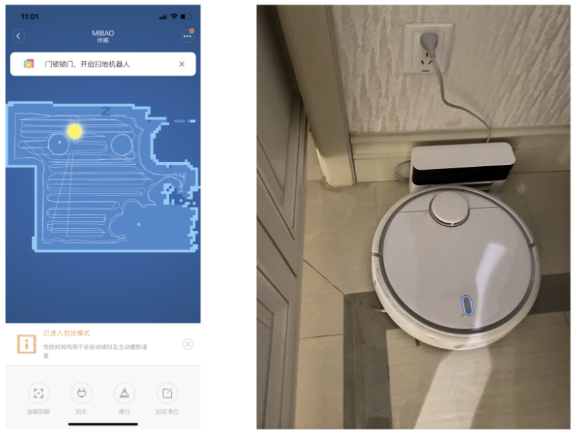


Figure 19: Screenshot of the app showing the vacuum robot automatically planning its way to the charging base and a picture of recharging vacuum robot

Symbolic domestication

1) Assurance of the basic cleaning

Since the vacuum robot is able to regularly clean up the room according to the schedule set by the user and does not require much human effort, it allows users to have the confidence of having the room with the basic cleaning. Thus, owning a vacuum robot represents to the user a guarantee of basic cleanliness.

P4: "At this price, he can basically meet my expectations for the cleanliness of the home. He can clean on his own, and does not require me to spend a lot of effort to maintain the basic cleanliness of the home."

2) A partner collaboratively finish the housework

With intelligence, vacuum robots are sometimes considered as cooperative partners for humans to complete household chores. Robots share the housekeeping practice of humans, allowing humans to multitask. Likewise, humans pre-cleanup the floor in order to leave the robot a flatter space to carry out the tasks.

P2: "He has greatly improved my efficiency in completing my daily chores, like sharing out the work. I'm cooking while he's helping me clean up my bedroom."

Figure 20: one of the participants is removing the objects that the vacuum robot will easily get stuck

Cognitive domestication

1) Able to trigger motivation on housework

The schedule set for the robot can sometimes affect the frequency of human participation in housework. The period during which the robot is working influences the user's mindset. Meanwhile, the user perceives this period as housework time and performs other housekeeping activities in addition to vacuuming. When the robot finished sweeping, one participant wondered why not mop the floor by the way. So every time the robot finished cleaning, he was prompted to incidentally mop the floor. Thus, in this case, the vacuum robot positively affected the user's motivation for housework.

P3:"Because of the scheduled cleaning mode, it motivates, sometimes even forces me to wet mopping the floor after the vacuum robot finishes its task every week."

2) Able to trigger users to form personalities of the robot to perceive its performance

In the interview, all the participants said they would give the robot human characteristics such as a nickname, personality, etc. This would make them more tolerant of the mistakes made by the robot. Some participants gave the vacuum robot an image based on the characteristics of the mistakes made by the robot. For example, the robot keeps getting stuck with the carpet and it is described by the participant as "he is falling in love with the carpet." Another example, one participant likened the situation where the sweeper robot kept spinning around in the same area to a toddler who needed constant coaching. They both said that these metaphors make the mistakes more amusing and tolerable to them. Moreover, some participants give nicknames to the vacuum robot integrating their liking and even cover the vacuum robot with a cloth to prevent dust.

P3:"It seems that my robot can fall in love with all the carpet in my home. I was like an evil stepmother. I split them up all the time...' You are not supposed to be together!!! She is not your true love!!! Go!!! Leave her, boy!!!' Then he just fell in love with another carpet. Bad boy. "

P1:"My dad named our vacuum robot MIBAO, which means the robot is his another baby"

Figure 21: The personalities that the participants give to the vacuum robot

Social domestication

1) Able to involve more family members in housework

Since the vacuum robot greatly simplifies the cleaning process, more family members are willing to participate in vacuuming the house —— simply press on the start button to complete the cleaning. In addition, as all family members share the same cleaning schedule of the vacuum robot, sometimes they need to adapt to each other's cleaning habits.

P1:"Everyone in the family has a different daily routine. Sometimes my father uses the vacuum robot in the morning, and it will automatically run to my room to wake me up"

2) Able to cooperate with the other smart devices within the family's ecosystem

The participants who were invited to complete the context diary owned vacuum robots from different brands. Some were able to connect with other smart home devices through the Internet, such as the Xiaomi sweeper, while others, on the contrary, were a traditional isolated sweeping device. During the interview, it was obvious to recognize that interviewees who had connected vacuum robots showed more fruitful stories with the robots and used them more frequently in their daily lives. In his words, *"I think it's a fun process to explore the conditions that trigger smart devices to each other like I would set in Smart Scene (a feature introduced in session 2.2.2) that when I start the running machine, the vacuum robot will start to clean. ..... It makes these smart devices more in line with my lifestyle."* This process extends the capabilities of vacuum robots through cooperation with other smart devices.

3.3 Creative session—Find out the possible predictive capabilities of vacuum robot

3.3.1 Objectives

1) Envisioning the possible predictive capabilities of vacuum robot;

2) Identifying the impacts when the predictive knowledge takes place;

3) Ideating the interaction of predicting vacuum robot;

4) Finding out the qualities that make the predicting vacuum robot acceptable in our life;

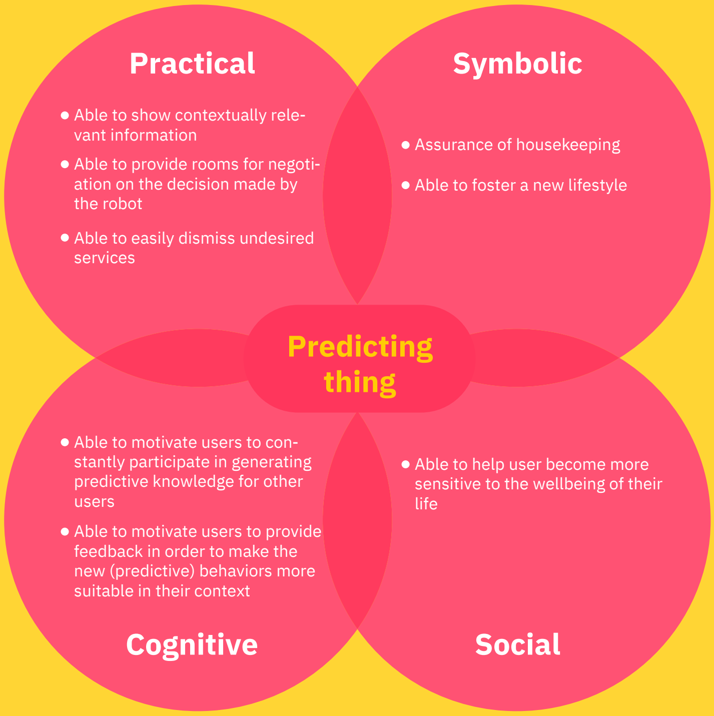
3.3.2 Method

Participants
4 participants who participanted in finishing the context diarys were invited to the creative session. Besides, 2 experts from the field of robotic and product design joined in to bring in the professional knowldege.

Structure
After sensitizing by the discussion of the context diary, 4 participants (who also finished the diary booklet) and 2 experts with robotics and design background will be invited to join a creative session to find out the possibilities of predictive capabilities. The project background will be first introduced to the participants and then they will be asked to envision and sketch the scenarios of the vacuum robot's predictive behavior. 3 sessions will focus on the objective 1, 2, and 3 (introduced in session 3.3.1) respectively. And then summarize the creative session through the domestication theory to find out the qualities for the acceptance of the predicting robot.be served as inspiration and presented in the group discussion.

1. Introduction of the project background (5mins)
2. Session1: Envision the possibilities
   a. Brainstorming & Sketching (5mins)
   b. Discussion (10mins)
2. Session2: Impacts
   a.Brainstorming & Sketching (5mins)
   b.Discussion (10mins)
4. Session3:Interaction
   a.Brainstorming & Sketching (5mins)
   b.Discussion (10mins)
5. End up

What qualities make Predicting thing (Predicting vacuum robot) become acceptable in our life?



3.3.3 Findings: Domestication qualities of predicting vacuum robot

Practical domestication

1) Able to show contextually relevant information

The ability to help the user to learn the reason behind the predictive behavior is crucial for the things that predict (Smit,2019). The Human-AI interaction guideline from Microsoft (Amershi et al., 2019) indicates one of the ways for expressing the reasons for predictions is to show the information that is related to the user's current environment and activity. This also can be proved from the creative session. Without guidance from the interviewer, the interactive dialogues with the predicting robot created by 4 participants all include the contextually relevant information to explain the robot's behavior. For example, in Figure 22, the robot provides the information that it is detected from the user's current behavior——smoking, and asks for permission to clean. Another storyboard shows that the robot points out the user will have a party and recommends cleaning in advance.

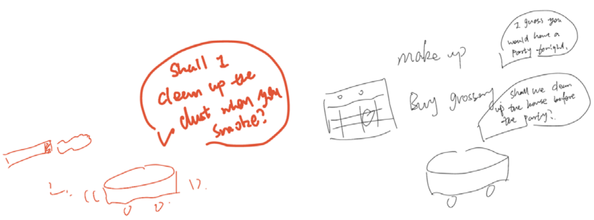


Figure 22: Participants' sketches of robot showing contextually relevent information

2) Able to provide rooms for negotiation on the decision made by the robot

When robots become intelligent or even able to predict, it is inevitable that they will need to make decisions autonomously at various degrees. These decisions may not always fit perfectly with the user's wishes. At this point, robots need to be able to negotiate, to revise their behavior, and even more advanced, to convince users to accept and understand their behavior. The negotiation process can also stimulate the user to provide the robot with more information to learn. As in the above example (Figure 22), when the robot is able to predict the user's potential needs, it asks the user and guides the user to give suggestions.

3) Able to easily dismiss undesired services

As the Figure 23 shows, one of the participants addresses the possible impact of the predicting vacuum robot: *"The robot may over-speculate my behavior."* In his vision, the predicting robot is like a student eager to update his knowledge pool through learning. The robot will constantly compare the data from the cloud with the scenario being served, which may offend the user or over-provide the service. Therefore, robots need to have the ability to easily dismiss undesired services.

Figure 23: Participants' sketches of the over-speculation of the robot

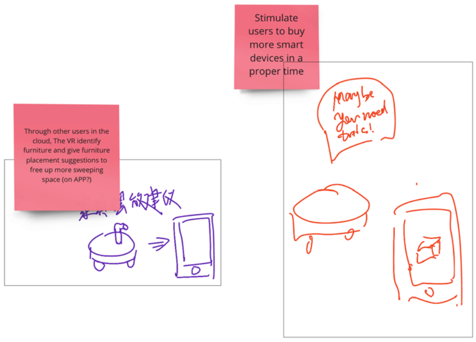


Figure 25: Participants' sketches of forstering new lifestyles

Symbolic dimension

1) Assurance of housekeeping

Unlike the current vacuum robot, which can only perform basic cleaning tasks, participants expect more comprehensive housekeeping from a robot that can gain more knowledge about household chores from other users. For example, based on reports of an increase in slip and fall accidents due to slippery floors, the robot issued a slippery floor warning. And keeps pets away from broken cups, etc. All of these indicate a shift from the vacuum robot, which now represents a guarantee of basic cleaning, to a symbol of more comprehensive housekeeping.

Figure 24: Participants' sketches of the housekeeping of vacuum robot

2) Able to foster a new lifestyle

As shown in the figure below, based on the fact that users now have a need for pre-clean, one participant suggested that through learning from the cloud, the vacuum robot is able to identify furniture and give suggestions on furniture placement to free up more sweeping space. Another participant proposed that predicting robots can hint and stimulate users to buy more smart devices in a proper time. The participants' expectations for the predicting robot were no longer limited to better housework, but extended to suggestions for new lifestyles——embracing new home layouts and new smart devices. They also said: *"(...) Compared to the current sweeper, I think if the predictive sweeper recommends new things to me from time to time, this will keep me fresh to him, so that the frequency of use may increase."*

Cognitive dimension

1) Able to motivate users to constantly participate in generating predictive knowledge for other users

A participant from a robotics company said, *"(...) As a developer of the robot, it is also an important part of our job to effectively collect user preference and feedback to enhance our system (...)"* Unlike current vacuum robot, predicting robot is not only a matter of encouraging users to be more involved, but also a matter of motivating them to pass on the knowledge they co-create with the robot to the cloud in order to enrich the knowledge base of the robot system to serve more people and make predictive behavior more relevant to people's demands. He added: *"(...) There are many ways to motivate users to donate their data, such as enabling them to understand what parts of the information they are about to share are desensitized. We also build a community of users to make them feel connected, and to let them realize how valuable their data donation is to the community (...)"*

2) Able to motivate users to provide feedback in order to make the new (predictive) behaviors more suitable in their context

This expert also said, *"(...) when the robot first predicts a new behavior through the cloud database, for example, that the robot predicts the user may need to clean the floor while smoking, the robot can ask for the user's opinion in a polite and questioning tone, and when this behavior is accepted by the user several times, the robot then performs the task with more initiative (...)"* (Figure 26) This process also allows the user to understand the underlying reasons for the predictive behavior of the robot and to adjust the nuances of the behavior to their own situation, e.g., sweeping the floor in a specific area around the user when the user is smoking. Through this process, the user changes from unfamiliar to this predictive behavior to familiar with it, and gradually delegates the initiative to the robot.

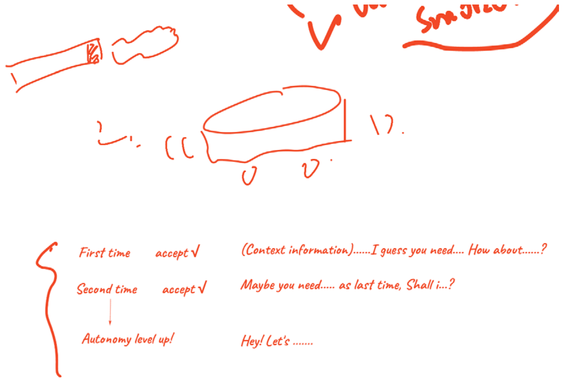


Figure 26: Participants' sketches of robot helping to learn about the predictive behavior

Social dimension

1) Able to help user become more sensitive to the wellbeing of their life

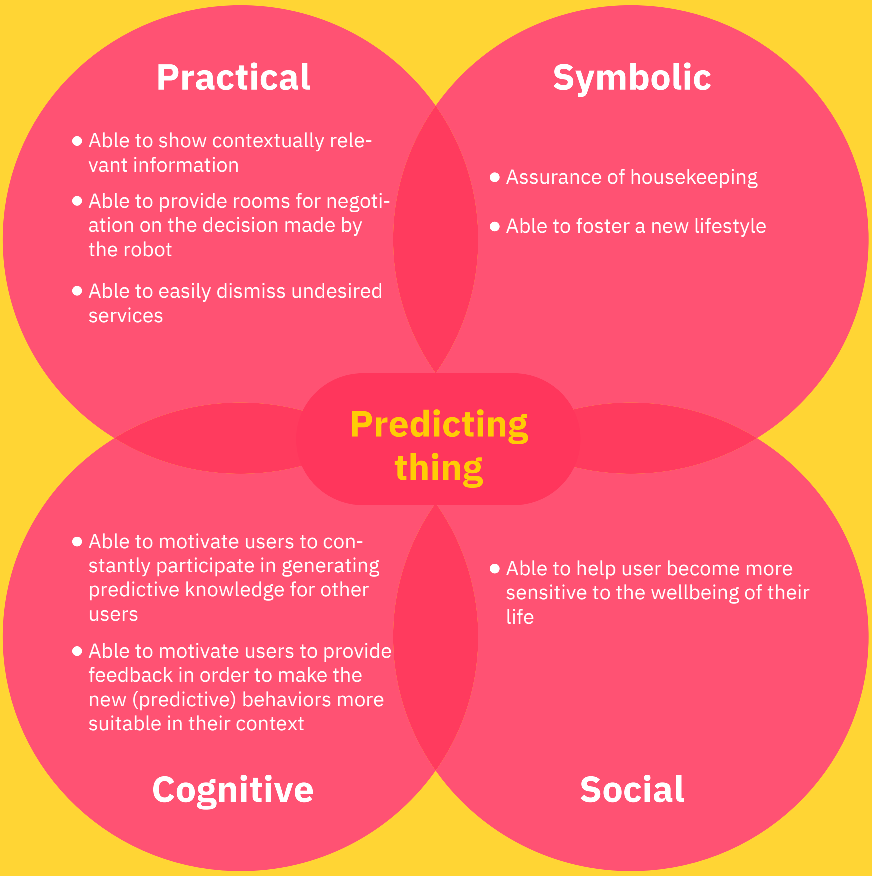
The reason for putting this quality in the social domestication instead of the cognitive domestication is that when the robot starts to predict behaviors that it learns from other users, the user will start to be influenced by the social comparison. They will compare their own lifestyle habits with those brought from other users, and thus pay more attention to the wellbeing of their life.

P5: "(...) it's like when I'm browsing a certain t-shirt on an online shopping platform, and the website gives me information that the person who viewed this t-shirt also bought this pair of jeans. Then I will start to think.... hmmmm...maybe having this pair of jeans to match the t-shirt would be nice. So, when I learn that prediction is learned from someone else, I will start to reflect on my own thoughts to think about whether it would be better to do that."

Key takeaways of Chapter 3

- **Domestication qualities as design qualities to implement the predictive behaviors**

The final results of the study in this chapter are the domestication qualities of predicting robots which will serve as design qualities for the acceptance of the predicting vacuum robot and will lead the performances of the prototype in the next chapter. Based on the domestication theory (Søraa et al., 2021; Berker, 2005; Lie and Sørensen, 1996), the study first investigates the qualities that make the current vacuum robot be adopted in our life. And results serve as the basis for identifying the qualities of predicting robots through the creative session. 8 qualities are divided into 4 dimensions and summarized as follows:



Category of predictive scenarios

Summarizing from the perspective of the starting point of the predictive behavior, the scenarios envisioned by the participants can be categorized as follows:

Predicting starts from sensing the environment

In this situation, the predicting robot will first sense the surrounding environment, then match the collected information with the data from the cloud to trigger the predictive actions. As discussed in Session 2.2.1, the vacuum robot can start from sensing the elements of the scene: the human actions, such as users' command and emotions, and recognizing the object like dust, etc.

Predicting directly start from the knowledge generated from the cloud users

The other way to trigger the predictive knowledge is that the predictions directly start from the cloud. Instead of triggering predictive behavior through the surroundings where the robot is embedded, in this situation, predictions are executed by obtaining knowledge directly from the cloud. For example, in Figure 27, the vacuum robot performs actions because of weather information and news reports.

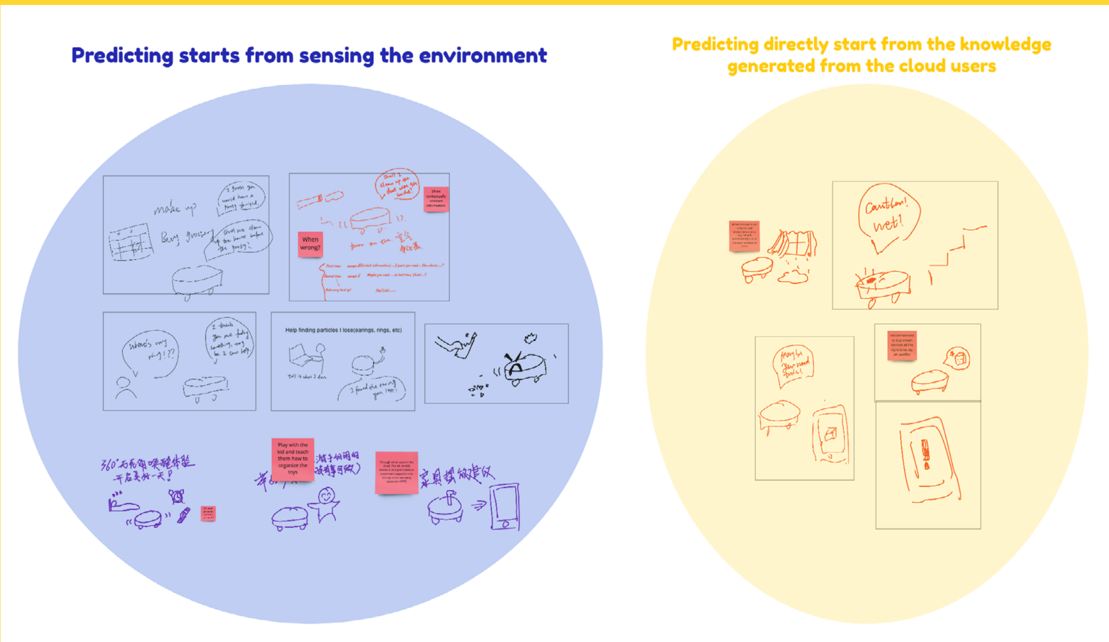
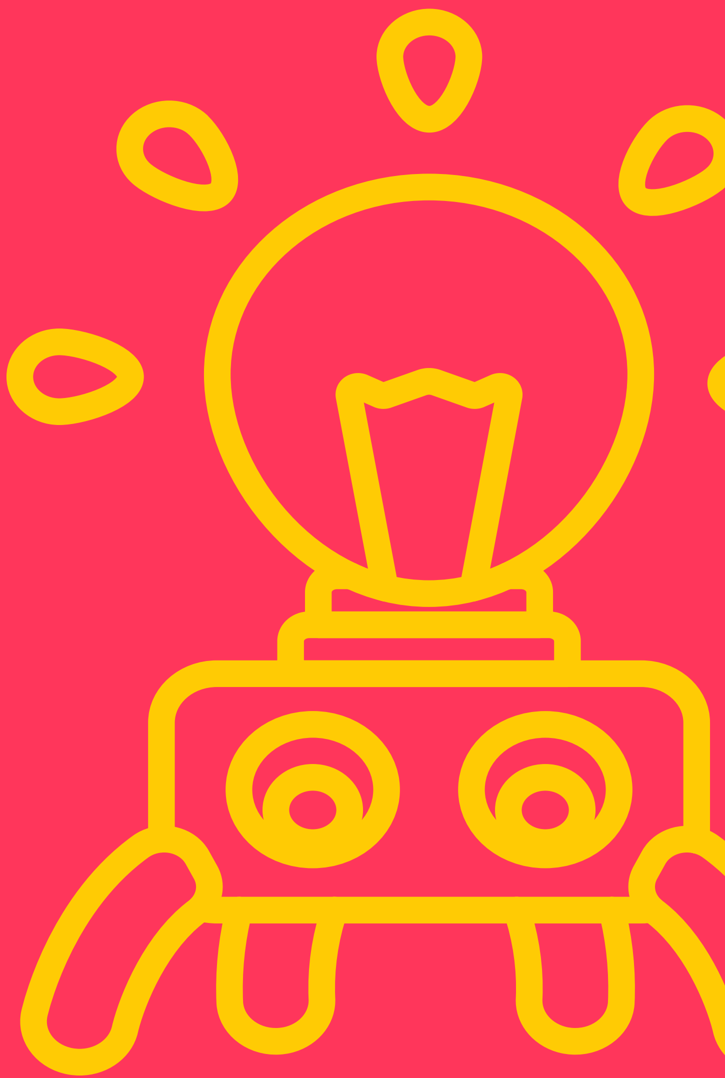


Figure 27: The category of predictive scenarios

Chapter overview



After envisioning the predicting vacuum robot, in this chapter, the discussion about the difference between the Adaptive system & the Predictive system in the autonomy determining process will be addressed. And then, synthesizing the results from previous chapters, a wireframe of generating predictive behavior will be proposed, indicating how a predictive behavior will be triggered and developed in the individual's context. After that, 2 propositions were set up to lead engaging the predictive behaviors through wizard of oz. Eventually, the scope and details of the wizard of oz will be described in this chapter.

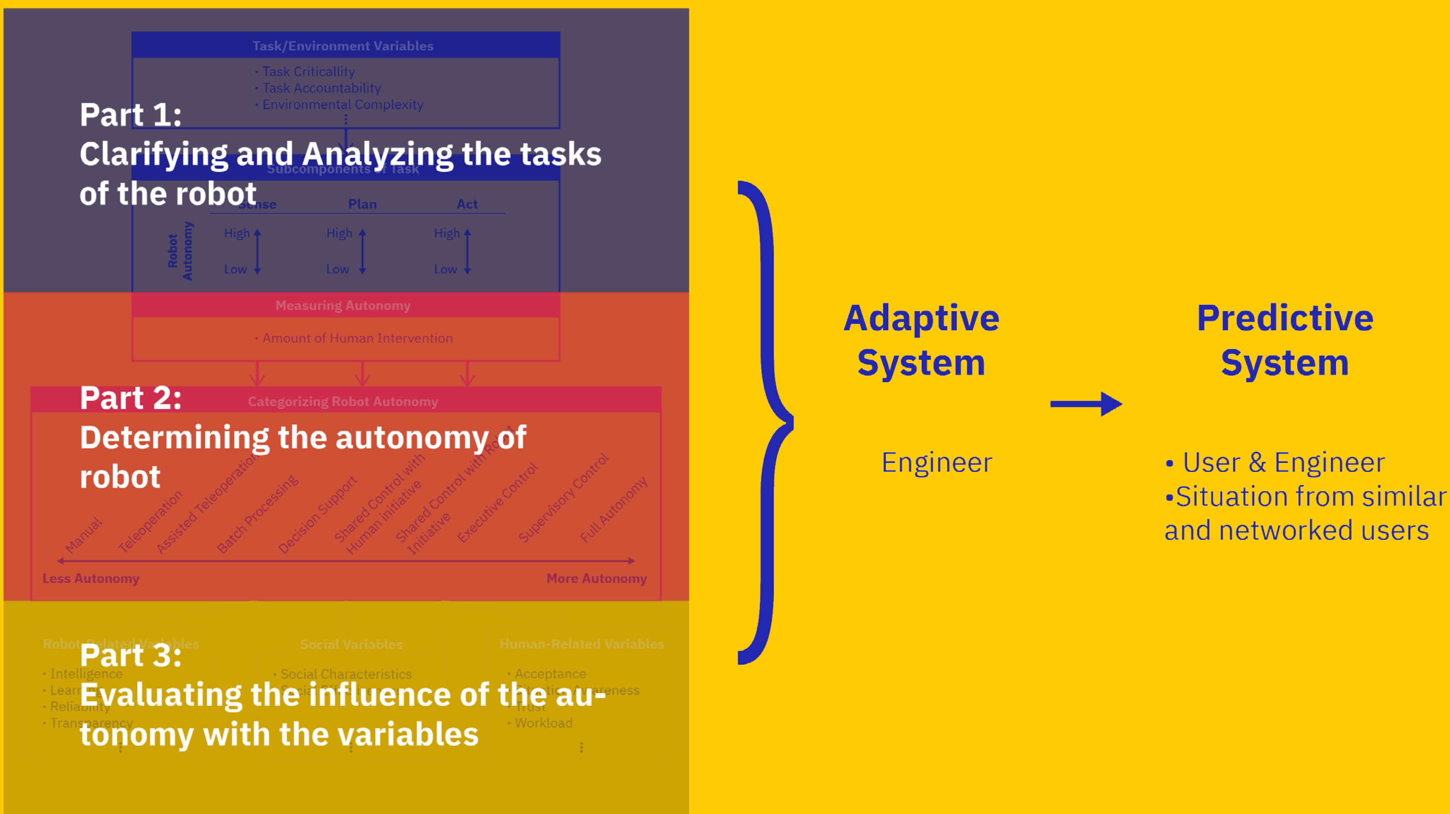
Chapter 4

Design proposal

4.1 Differences between Adaptive system & Predictive system in autonomy determining process

In Smit's article, he makes a distinction between how an adaptive system and a predictive system acquire knowledge(Smit, 2020). An adaptive system is the intelligent system performing scripted behavior and adapting users' behavior based on the stored patterns set up by the experts. However, a predictive system carries out the profile co-created by the other similar networked users and steer co-performance.

With the differences in mind, this project proposes the process of determining autonomy of predicting robots based on Beer's framework. In the adaptive system, engineers play a crucial role in analyzing the tasks and determining the autonomy level of the robot. After defining the smart product, they are also responsible for evaluating the rationality of the robot's behavior. However, in the predictive system, the roles of planning the tasks and justifying the appropriate initiative are highly dependent on the knowledge generated from similar and networked users. In this system, users are not only engaged as the ones using the products but also as the ones participating in the evaluation, making the predictive behavior more appropriate and suitable for more people through the involvement of a wide variety of users.



4.2 Wireframe of generating predictive behavior

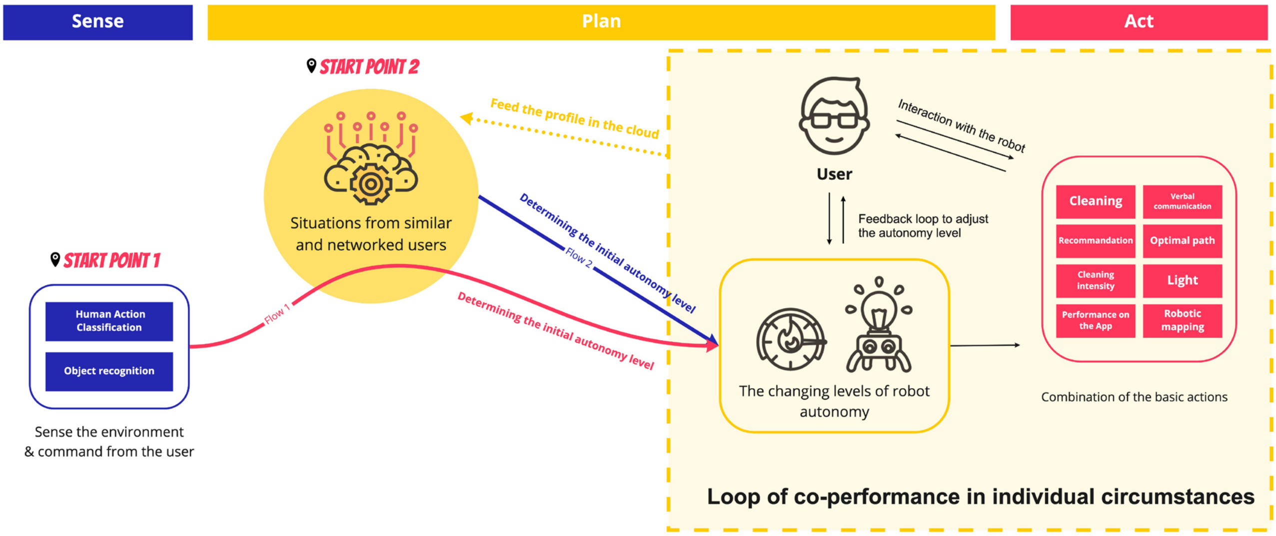


Figure 28: Wireframe of generating predictive behavior

Based on the process described in Session 4.1, a wireframe is proposed to visualize the process of generating the predictive behavior. In this wireframe, according to the findings in Chapter 3, there are 2 ways to trigger the prediction: 1) starting from robots sensing the environment and the users' command, 2) directly starting from the knowledge generated from the cloud users. As Figure 28 shows, the only difference between these two processes is that the former one has one more step than the latter one, i. e. sensing the user's environment.

When the prediction begins from collecting the data from the environment, the predicting robot will then match the collected information with the data from the cloud to interpret and understand the scene. Based on the cloud knowledge and user's past experience, the robot will determine the initial autonomy level when this predictive behavior first takes place in the context and perform actions with the corresponding level of automation. The interaction between humans and robots will create a loop of co-performance where human performers and robot performers together judge and shape the appropriate performance under individual situations (Kuijer & Giaccardi, 2018). Through the co-performance, the predictive behavior will be gradually adjusted and adapted to the specific circumstances, and the data generated from this loop will also feed forward the profile in the cloud.

4.2.1 The changing levels of robot autonomy in the loop of co-performance

Kuijer and Giaccardi define the co-performance in the view that artifacts have the human-like capabilities to learn and judge the tasks in the interplay with humans (Kuijer & Giaccardi, 2018). In the traditional procedure of developing smart things, the performances of the devices are being determined in the design process. However, in the concept of 'co-performance', the process of defining the performances of the things is shifted to the everyday use practice, which creates an open space for humans and things to learn and adapt to the appropriate performances in their daily practice. The distribution of the agency and the robot's autonomy, however, are the result of this dynamic learning and adapting process. Thus, with this definition in mind, this project proposes that the autonomy level of the predictive behavior situated in the loop of co-performance, will be dynamically changed by the interplay between humans and robots. The human judges whether a particular predictive behavior is appropriate, and through interplay with the robot, the predictive behavior becomes more in line with his or her personal expectations. In this process, the labor distribution between humans and robots is also changing, thus implicitly affecting robot's autonomy. Also, since the interplay reveals the learning process, the understandability and trust of the predictive behavior will increase.

4.3 Proposition

According to Session 4.2 and Session Session 3.4.1, 2 propositions are proposed and lead the design and evaluation:

Proposition 1

The loop of co-performance in the proposed wireframe, will result in the changing autonomy level and help to increase the understandability and trust of the predictive behavior.

Proposition 2

The domestication qualities indicate how the predictive knowledge of the vacuum robot is being implemented and accepted in our life

4.4 Engaging the predictive behaviors through wizard of oz

Based on the 2 different starting points of generating the predictive behavior in the proposed wireframe, two scenarios are set up to build up the prototypes of the predicting vacuum robot. The prototypes are in the form of wizard of oz which aims at engaging the predictive behavior of the vacuum robot and evaluating the propositions. The procedure for the wizard of oz is shown as follow (Figure 29):

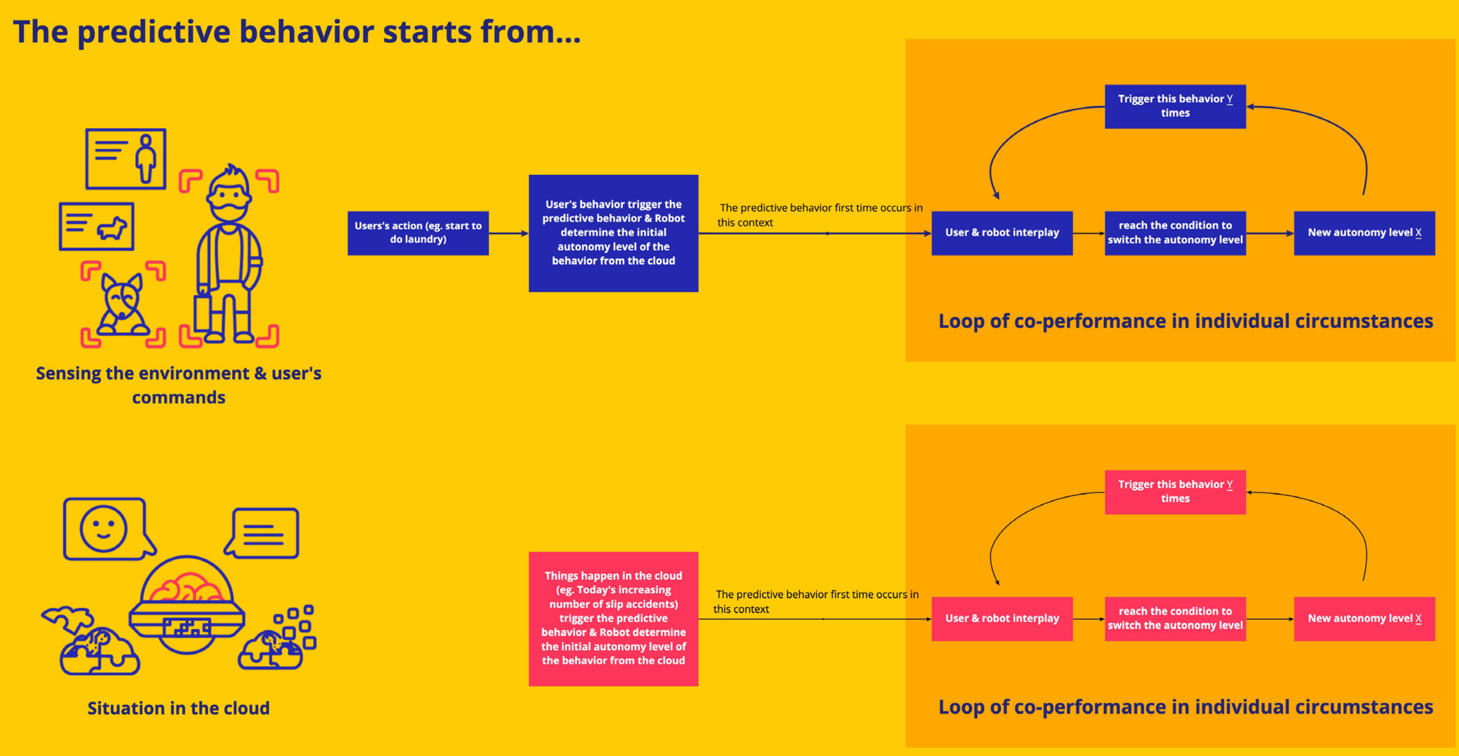


Figure 29: The procedure for the wizard of oz

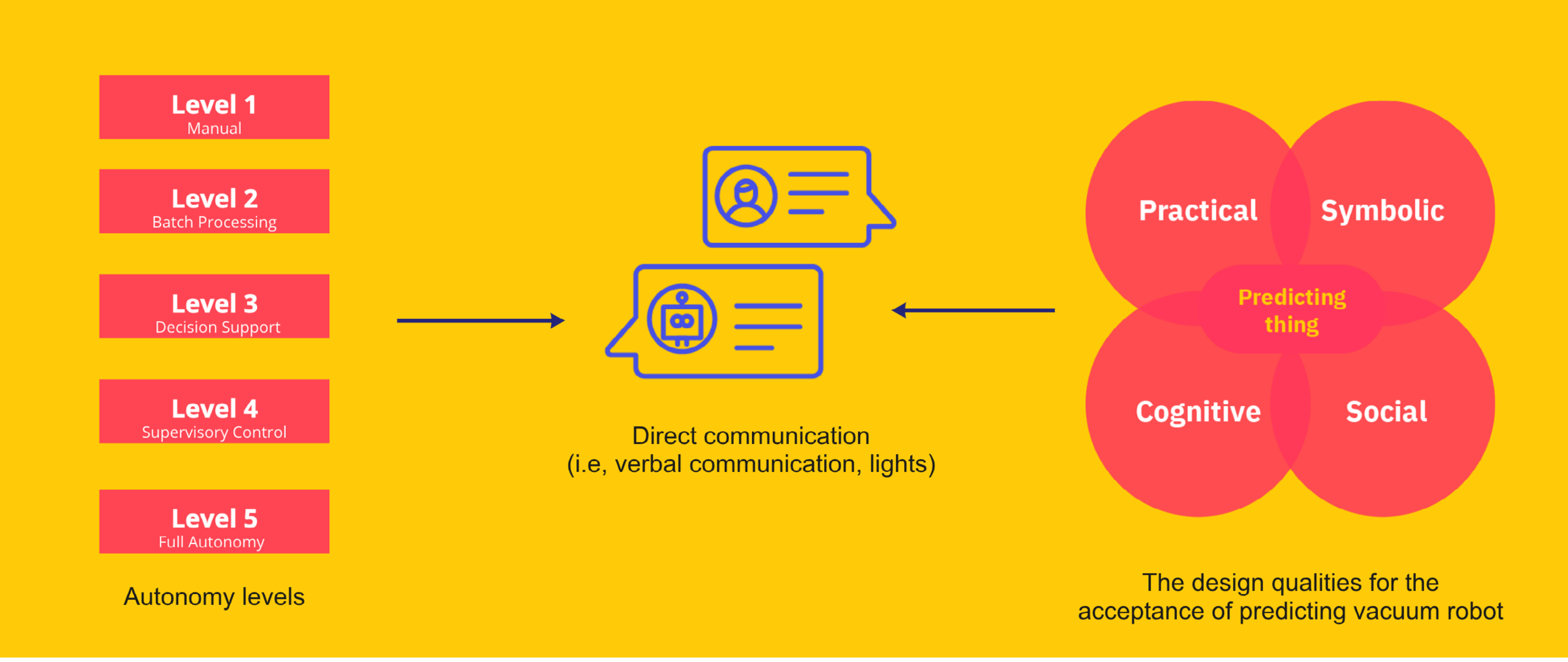


Figure 30: 2 elements influence the direct communication

4.4.1 Scope

In the procedure (Figure 29), the interplay between the user and the vacuum robot affects the autonomy of the robot, which leads to changes in the autonomy level. As suggested in Chapter 2, the autonomy levels will be simplified as 5 levels and across from manual to full autonomy:

- **Level 1: Manual**
  The human carries out all aspects of the task including sensing the environment, generating plans, and performing actions.

- **Level 2: Batch Processing**
  The environment is monitored and sensed by both the human and robot. However, the human sets the goal and plan of the task. The robot then performs the task.

- **Level 3: Decision Support**
  The environment is monitored and sensed by both the human and robot. However, different from Batch Processing, the robot provides the choices of plans and actions for the human to choose

- **Level 4: Supervisory Control**
  The robot performs all aspects of the task, but the human continuously monitors the robot and sets a new goal and plan. If the robot encounters difficulty, it can prompt the human for assistance

- **Level 5: Full autonomy**
  The robot performs all aspects of the task without human intervention, generates new goals and plans, and then implements them by itself.

Besides, the wizard of oz will focus on the physical interaction of the vacuum robot, i.e, verbal communication, lights on the robot. The domestication qualities will serve as the design qualities to guide prototyping the physical interaction. In conclusion, how the vacuum robot performs the predictive behavior will be influenced by 2 elements: 1) Autonomy levels, 2) the domestication qualities of predicting vacuum robots (Figure 30).
For ease of later expression, each quality is labeled with a serial number:

Practical domestication

1. Able to provide rooms for negotiation on the decision made by the robot.
2. Able to easily dismiss undesired services.
3. Able to show contextually relevant information.

Symbolic domestication

4. Assurance of housekeeping.
5. Able to foster a new lifestyle.

Cognitive dimension

6. Able to motivate users to constantly participate in generating predictive knowledge for other users.
7. Able to motivate users to provide feedback in order to make the new (predictive) behaviors more suitable in their context.

Social dimension

8. Able to help user become more sensitive to the wellbeing of their life

> Scenario 1

Predictive behavior start from sensing the environment & user's command

Trigger: Amy is doing laundry

Amy is a housewife living with her husband, a two-year-old little boy and a cat. The family has just gotten a vacuum robot and they are still curious about this new creature. And now, It's 9 o'clock in the morning and it is springtime. Amy is planning to wash and put away her winter covers as usual...

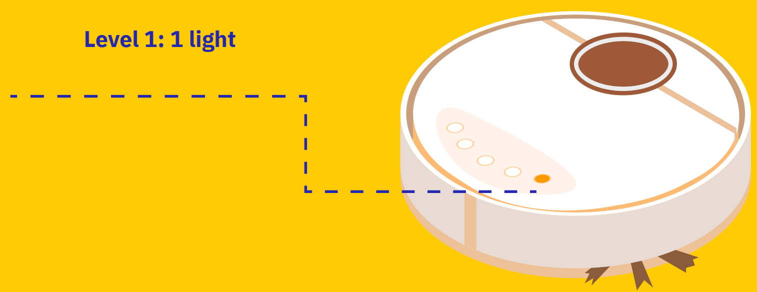
Level 1
Manual

Sense	H
Plan	H
Act	H

The human carries out all aspects of the task including sensing the environment, generating plans, and performing actions.

Key verbal dialogue from the robot

Before the robot starting to work	None
After finishing all the tasks	Jobs done !
Condition to switch the levels	User commands



Level 2
Batch Processing

Sense	H/R
Plan	H
Act	R

The environment is monitored and sensed by both the human and robot. However, the human sets the goal and plan of the task. The robot then performs the task.

Key verbal dialogue from the robot

Before the robot starting to work

Question 1: I think...*(Contextually relevant information)*. It seems i can help. Shall i do something for you?

if "Yes"

Question 2: Ok, ...*(Ask for the plans/actions)* ?

After finishing all the tasks

Question 3: Jobs done! Hey, it seems we both enjoy our cooperation this time. This cleaning scene will largely improve my system and help more people. Are you willing to save this anonymously in the cloud?

User answer for Question 1

if "No" → Level 1

if "No"

Question 4: If you want to dismiss this cleaning scene or remind you next time?

if "Dimiss" → Level 1

if "Next time" → Same level next time

if "Yes" → Upgrade the levle

Condition to switch the levels

Example of dialogue in Scenario 1

Question 1 Qualities: 2 3 5

(Beep) I think you are doing laundry, It seems i can help at the same time. Shall i do something for you?

if "Yes" →

Question 2 Qualities: 7

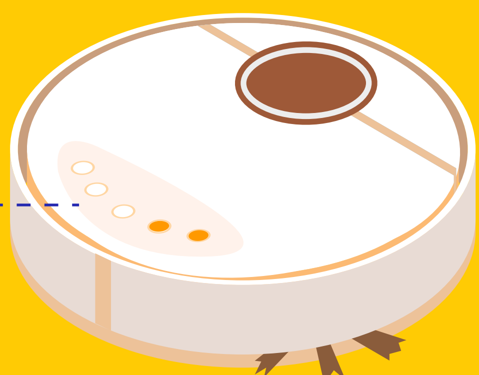
Ok, How would you want to clean up the room?

Beep
(when upgrading the level)

Question 3 Qualities: 6

Jobs done! Hey, it seems we both enjoy our cooperation this time. This cleaning scene will largely improve my system and help more people. Are you willing to save this anonymously in the cloud?

Level 2: 2 lights
(Twinkle when adjusting the level)



Level 3
Decision Support

Sense	H/R
Plan	H/R
Act	R

The environment is monitored and sensed by both the human and robot. However, different from Batch Processing, the robot provides the choices of plans and actions for the human to choose.

Key verbal dialogue from the robot

Before the robot starting to work

Question 1: I think...*(Contextually relevant information)*. Maybe it would be a good idea to ...(Actions/Plans). Shall i start to...*(Actions/Plans)*? or you have a better idea?

if "Yes"

Question 2: Ok, *(Provide suggestion & choices)*

After finishing all the tasks

Question 3: Jobs done! Hey, it seems we both enjoy our cooperation this time. This cleaning scene will largely improve my system and help more people. Are you willing to save this anonymously in the cloud?

User answer for Question 1

if other command → Degrade the levle

if "No" → **Question 4:** If you want to dismiss this cleaning scene or remind you next time?

- if "Dimiss" → Level 1
- if "Next time" → Same level next time

if "Yes" → Upgrade the levle

Condition to switch the levels

Example of dialogue in Scenario 1

Question 1 Qualities: 1 2 3 5

(Tone) I think you are doing laundry, Maybe it would be a good idea to clean up the floor at the same time. Shall I start to clean now? Or you have a better idea?

if "Yes" →

Beep
(when upgrading the level)

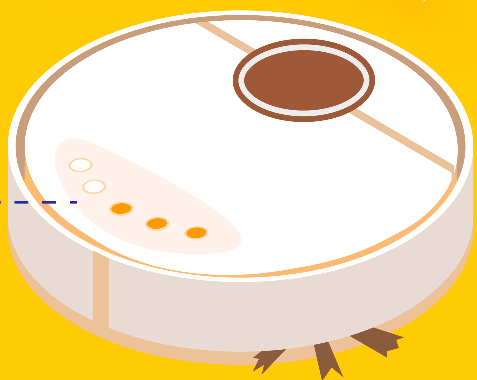
Question 2 Qualities: 7 8

OK, since now it's the shedding season of cats. As it has been proved useful by the others, I suggest clean up the bedroom with strong mode to reduce the possibilities of allergy. Shall I?

Question 3 Qualities: 6

Jobs done! Hey, it seems we both enjoy our cooperation this time. This cleaning scene will largely improve my system and help more people. Are you willing to save this anonymously in the cloud?

Level 3: 3 lights
(Twinkle when adjusting the level)



Level 4
Supervisory Control

Sense	H/R
Plan	R
Act	R

The robot performs all aspects of the task, but the human continuously monitors the robot and sets a new goal and plan. If the robot encounters difficulty, it can prompt the human for assistance.

Key verbal dialogue from the robot

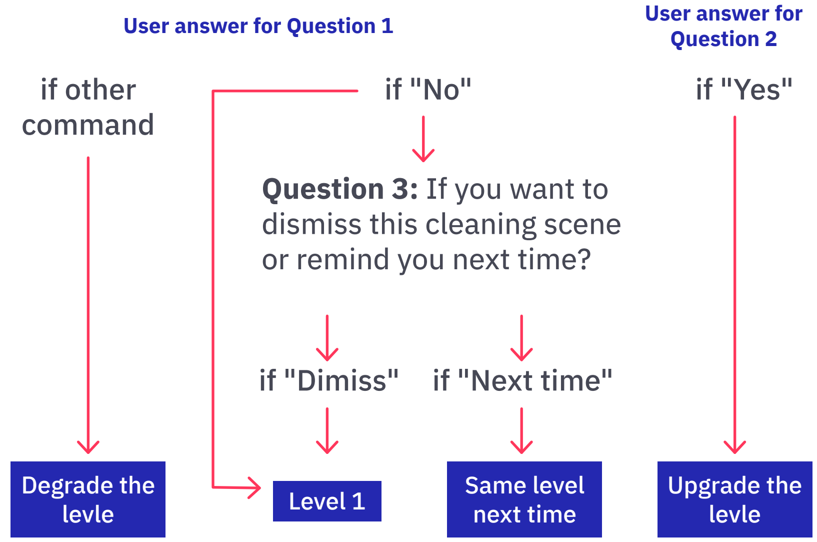
Before the robot starting to work

Question 1: Maybe it's time for ...*(Actions/Plans)*. Shall i start to...*(Actions/Plans)*?

After finishing all the tasks

Question 2: Jobs done! Hey, I have completed the *(cleaning scene)* for *XX* times. I think i am the master of this now. Should I perform this cleaning scene directly next time?

Condition to switch the levels



Example of dialogue in Scenario 1

Question 1 Qualities: 2 5

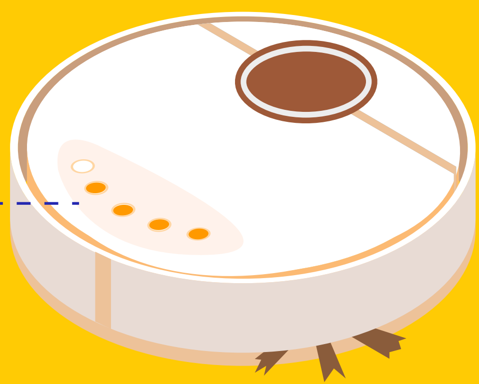
(Beep) Hey, I think you are doing laundry . Maybe it's time for clean up the room. Shall I start to clean up the room with the same setting of last time?

Question 2 Qualities: 4 6

Jobs done! Hey, I have completed the cleaning when you doing laundry for 5 times. I think i am the master of this now. Should I perform this cleaning scene directly next time?

Beep
(when upgrading the level)

Level 4: 4 lights
(Twinkle when adjusting the level)



Level 5
Full Autonomy

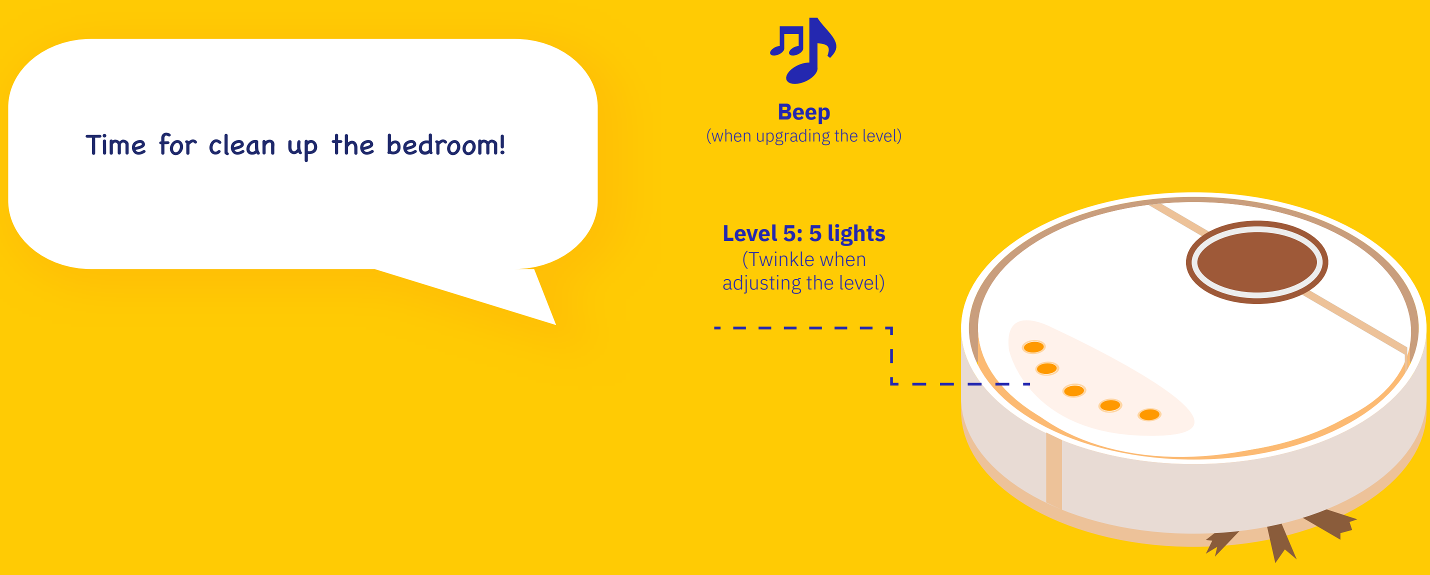
Sense	R
Plan	R
Act	R

The robot performs all aspects of the task without human intervention, generates new goals and plans, and then implements them by itself.

Key verbal dialogue from the robot

Before the robot starting to work	Time for/Start to.... *(Actions/plans)*
After finishing all the tasks	Jobs done !
Condition to switch the levels	User commands

Example of dialogue in Scenario 1



> Scenario 2

Predictive behavior start from the knowledge generated from the cloud users

Trigger: The number of slip and fall accident increased in the city

Susan is an elder living alone and her children are working far away from her. In order to make her life more convenient, her children bought her a vacuum robot recently. It's the beginning of summer, and it's raining outside. Susan is reading today's morning newspaper by the window...

Level 1
Manual

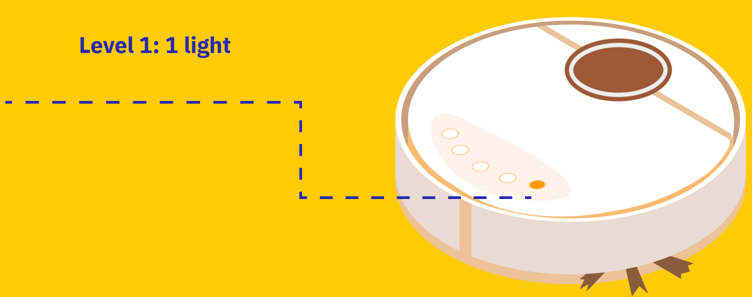
Sense	H
Plan	H
Act	H

The human carries out all aspects of the task including sensing the environment, generating plans, and performing actions.

Key verbal dialogue from the robot

Before the robot starting to work	None
After finishing all the tasks	Jobs done !
Condition to switch the levels	User commands

Level 1: 1 light



Level 2
Batch Processing

Sense	H/R
Plan	H
Act	R

The environment is monitored and sensed by both the human and robot. However, the human sets the goal and plan of the task. The robot then performs the task.

Key verbal dialogue from the robot

Before the robot starting to work

Question 1: Caution slippery floor!......*(Contextually relevant information)*. It seems i can help. Shall i do something for you?

if "Yes"

Question 2: Ok, ...*(Ask for the plans/actions)* ?

After finishing all the tasks

Question 3: Jobs done! Hey, it seems we both enjoy our cooperation this time. This cleaning scene will largely improve my system and help more people. Are you willing to save this anonymously in the cloud?

User answer for Question 1

if "No"

Question 4: If you want to dismiss this cleaning scene or remind you next time?

if "Dimiss" → Level 1

if "Next time" → Same level next time

if "Yes" → Upgrade the levle

Condition to switch the levels

Example of dialogue in Scenario 2

Question 1 — Qualities: 2 3 5 8

(Beep) Caution slippery floor! Due to the wet weather, according to the city's news, there are frequent slip and fall accidents among the elderly today. It seems i can help. Shall i do something for you?

if "Yes"

Question 2 — Qualities: 7

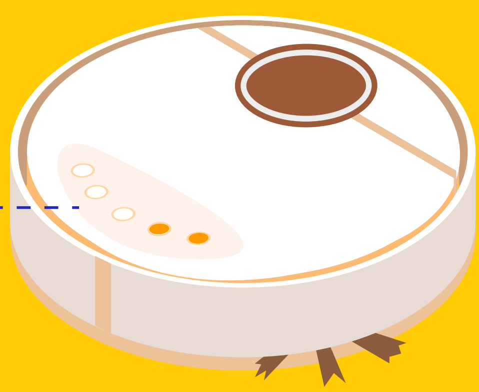
Ok, What would you want me to do?

Beep
(when upgrading the level)

Question 3 — Qualities: 6

Jobs done! Hey, it seems we both enjoy our cooperation this time. This cleaning scene will largely improve my system and help more people. Are you willing to save this anonymously in the cloud?

Level 2: 2 lights
(Twinkle when adjusting the level)



Level 3
Decision Support

Sense	H/R
Plan	H/R
Act	R

The environment is monitored and sensed by both the human and robot. However, different from Batch Processing, the robot provides the choices of plans and actions for the human to choose.

Key verbal dialogue from the robot

Before the robot starting to work

Question 1: Caution slippery floor!...*(Contextually relevant information)*. I would suggest ...*(Actions/Plans)*. Shall i start to...*(Actions/Plans)*? or you have a better idea?

if "Yes"

Question 2: Ok, *(Provide suggestion & choices)*

After finishing all the tasks

Question 3: Jobs done! Hey, it seems we both enjoy our cooperation this time. This cleaning scene will largely improve my system and help more people. Are you willing to save this anonymously in the cloud?

User answer for Question 1

Condition to switch the levels

- if other command → Degrade the levle
- if "No" → **Question 4:** If you want to dismiss this cleaning scene or remind you next time?
  - if "Dimiss" → Level 1
  - if "Next time" → Same level next time
- if "Yes" → Upgrade the levle

Example of dialogue in Scenario 2

Question 1 Qualities: 1 2 3 4 5 8

(Tone) Caution slippery floor! Due to the wet weather, according to the city's news, there are frequent slip and fall accidents among the elders today. I would suggest mopping the areas that are prone to be damp and alerting before the floor dries. Shall i start t to mop up now? or you have a better idea?

if "Yes"

Beep
(when upgrading the level)

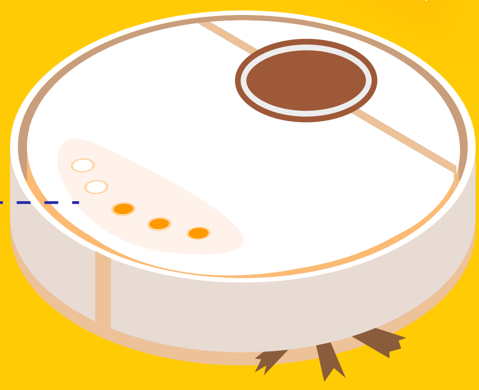
Question 2 Qualities: 4 7 8

OK, According to the Internet, the most likely places for the elderly to fall in wet weather are toilet and the area around the stairs, so I suggest mopping up these two places. Shall I?

Question 3 Qualities: 6

Jobs done! Hey, it seems we both enjoy our cooperation this time. This cleaning scene will largely improve my system and help more people. Are you willing to save this anonymously in the cloud?

Level 3: 3 lights
(Twinkle when adjusting the level)



Level 4
Supervisory Control

Sense	H/R
Plan	R
Act	R

The robot performs all aspects of the task, but the human continuously monitors the robot and sets a new goal and plan. If the robot encounters difficulty, it can prompt the human for assistance.

Key verbal dialogue from the robot

Before the robot starting to work

Question 1: Caution slippery floor! ...(Actions/Plans). Shall i start?

After finishing all the tasks

Question 2: Jobs done! Hey, I have completed the *(cleaning scene)* for *XX* times. I think i am the master of this now. Should I perform this cleaning scene directly next time?

Condition to switch the levels

User answer for Question 1

if other command → Degrade the levle

if "No" → **Question 3:** If you want to dismiss this cleaning scene or remind you next time?

- if "Dimiss" → Level 1
- if "Next time" → Same level next time

User answer for Question 2

if "Yes" → Upgrade the levle

Example of dialogue in Scenario 2

Question 1 — Qualities: 2 4 8

(Tone) Caution slippery floor! Planning to mop the toilet and alert in the surrounding area before the floor dries. Shall i start?

Question 2 — Qualities: 4 7

Jobs done! Hey, I have completed the cleaning when you doing laundry for 5 times. I think i am the master of this now. Should I perform this cleaning scene directly next time?

Beep
(when upgrading the level)

Level 4: 4 lights
(Twinkle when adjusting the level)

Level 5
Full Autonomy

Sense	R
Plan	R
Act	R

The robot performs all aspects of the task without human intervention, generates new goals and plans, and then implements them by itself.

Key verbal dialogue from the robot

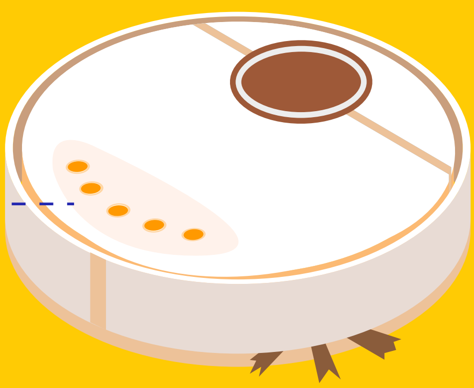
Before the robot starting to work	Caution slippery floor! Start to.... *(Actions/plans)*
After finishing all the tasks	Jobs done !
Condition to switch the levels	User commands

Example of dialogue in Scenario 2

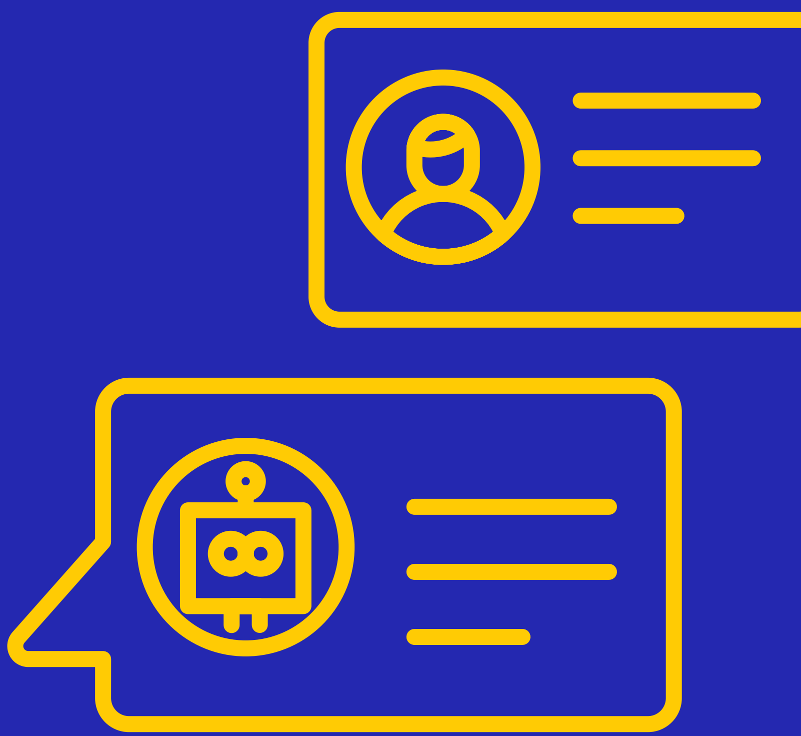
Caution slippery floor! Start to mop up the toilet!

Beep
(when upgrading the level)

Level 5: 5 lights
(Twinkle when adjusting the level)



Chapter overview



This chapter presents the process, method, and results of the evaluation with 8 participants with design backgrounds. The insights gained from this session lead to the modified version of design qualities and the idea of designers as the facilitator of human-robot collaboration.

Chapter 5

Evaluation

5.1 Objective

The evaluation aims to evaluate the effect of the design proposal for the predictive behavior and the validity of the propositions generated from phase 2. The propositions and research questions of each proposition are as follow:

Proposition1

The loop of co-performance in the proposed wireframe, will result in the changing autonomy level and enhance the transparency of predictive behavior.

- RQ1: Can the loop of co-performance increase the understandability of the predictive behavior?
- RQ2: Can the loop of co-performance increase the trust of the predictive behavior?

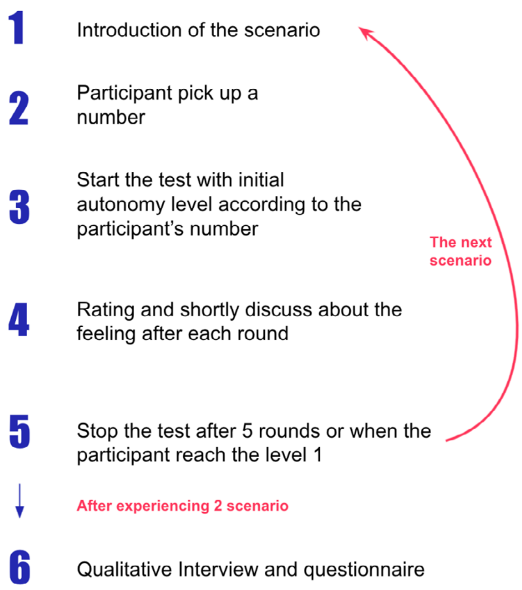
Proposition 2

The qualities indicate how the predictive knowledge of vacuum robot being implemented and adapted in our life

- RQ3: Can the users recognize the qualities from the prototype?
- RQ4: Can the qualities help the users accept the predictive behavior of the vacuum robot?

5.2 Method & Process

Participant number		1&2	3&4	5&6	7&8
Initial autonomy level	Scenario 1	Level 2	Level 3	Level 4	Level 5
	Scenario 2	Level 2	Level 3	Level 4	Level 6



To validate the propositions, 8 participants with design background will be invited to the evaluation test and each test will be operated individually. One of the scenarios will be first introduced to the participant. And then the participant will be asked to pick up a number. To simulate the situation that the predictive behavior will occur in different autonomy levels in reality, the participants will experience the introduced scenario and randomly start with a certain autonomy level according to the number they have picked up. During the test, the interviewer will act upon the robot's behavior according to the current autonomy level. Each round of interaction will be ended up when the robot has finished certain tasks and the participant will be asked to score their feeling on the robot's cleaning decision. If the participant reaches the conditions of switching the autonomy level, the interviewer will perform the behavior of the new autonomy level next round. The test of each scenario will stop after 5 rounds or when the participant reaches level 1. A qualitative interview will be conducted after the end of the 2 scenarios.

Figure 31: Participants taking the evaluation via Zoom call

5.3 Materials

Due to the limitation of COVID-19, the evaluation is implemented entirely online. For acting out the predictive behavior of the vacuum robot, this project uses PowerPoint to present the keyframe of each autonomy level of the 2 scenarios. To best simulate the scenarios, on the left-hand side, there is a helicopter view of the home environment to provide more information for participants to engage in the interaction. The preset dialogues will serve as the guide for the researcher to improvise the conversation and switch the autonomy levels in certain conditions.

5.4 Measures

For proposition 1

The evaluation results of proposition 1 will be delivered by combining the insights of quantitative and qualitative research

Quantitative research:

- The tendency of the rate of understandability after 5 rounds of interaction
- The tendency of the rate of trust after 5 rounds of interaction

Why measure the rate of understandability and trust?

Understandability

Transparency can be referred to the explainability of one system and to what extent the user can understand and interpret the decision-making process of one system (Felzmann et al., 2020). Thus, the user's understandability of the decision made by the predicting robot is one of the most relevant criteria of transparency in the evaluation.

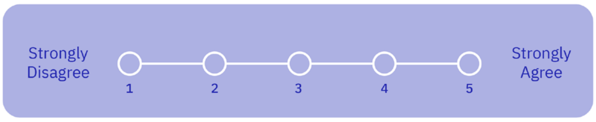
Trust

Transparency is considered as one of the highly relevant factors of trust in automation. However, trust is a more general feeling that is not only affected by the understandability of the automation process but also constructed by performance expectancy and task context (Chien, 2016). By measuring trust and asking the reason behind the rate can lead the qualitative interview with the participants to a more open discussion about their emotional feelings and experiences of different rounds.

Each round of interaction will be ended up when the robot has finished certain tasks and the participant will be asked to vote on the degree of understandability and trust of the robot's cleaning decision. The tendency of the rates will serve as a reference to figure out the change of understandability and trust during the interaction with the robot and lead the qualitative interview.

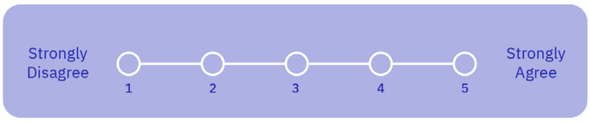
Measuring the understandability of each round

It is clear to me why the robot offered to clean.



Measuring the trust of each round

It's trustworthy to me for the cleaning decisions made by the robot.



Qualitative research:

Open-ended questions for proposition 1 are added in the qualitative interview after the test to collect the participants' opinions on the experience of each round. (see Appendix G)

For proposition 2

- Open-ended questions after the test (see Appendix G)
- Questionnaires for the qualities (see Appendix G)

After participants have experienced 2 scenarios, a qualitative interview will be conducted to ask about their general experience and the acceptance of the predictive behavior. Also, to evaluate if the qualities are valid and recognizable in the design, the specific questions and questionnaires for 4 dimensions of the qualities are set up respectively. The result of the questionnaires will lead the interview.

5.5 Results

5.5.1 Evaluation results of Transparency

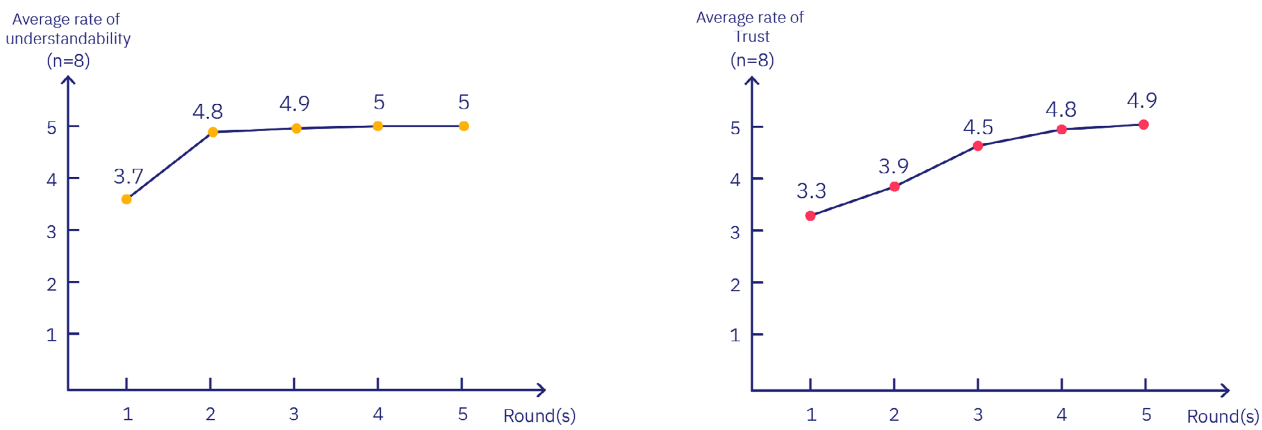


Figure 32: The image of the average rate of participants' understandability and trust in robot's cleaning decisions

1) General

The understandability and trust of the predictive behavior increased through the loop of co-performance

According to Figure 32, after 5 rounds of interaction, the participants' rate of understandability and trust in the cleaning decisions made by the vacuum robot was gradually increasing. They described the reasons for the changes during the process as:

"The process is like gradually building trust in a partnership. At first, when he started working on his own, I didn't quite understand, so I interrupted him and asked him why, and his explanations were able to convince me and integrate my instructions into his work, which made me feel that he was becoming more trustworthy"

"I feel like it's a learning process. I mean not only is he adjusting the suggestions he gives me based on my response to him, but I'm also learning the reasoning behind what he's doing in the process"

They also indicated that after a few rounds they were willing to leave the work alone:

" I may need him to give me the background information on doing so at the beginning, but then I just let them be, and it frees me up."

The overall experience with the predictive behaviors is supportive

During the evaluation, the adjectives that participants used most often to describe their relationship with the vacuum robot were supportive and collaborative. They described the vacuum robot with predictive knowledge as a supportive partner that provides the surprises.

"He may bring my attention to the details that I may not notice in my daily life."

One participant emphasized his liking for the unexpected action of the robot
after asking how the robot in Scenario 2 would have alerted before the ground was completely dry.

"I never thought that the indicator light of the vacuum robots could be used in this way before."

The purpose of lights on the robot and beep requires instruction beforehand

During the test, only a few participants noticed the lights and beep, and few were able to clearly illustrate their purpose. The reason for this may be partly explained by the limitations of the online platform, but also by the lack of advanced instructions.

"I heard the beep from the robot, but not paying too much attention to it. I guess it probably indicated the robot was planning to do something (which is not the exact purpose of the beep). I think it would help if it has some introduction about this."

2) Understandability of the predictive behavior

Participants can recognize why the prediction happens and how it is being generated

After five rounds of interaction, most participants were able to roughly indicate the reasons for the robot's cleaning decisions and to anticipate how each of their responses would change the robot's behavior the next time.

"...... In the beginning, it seemed like my act of going to the laundry triggered his actions, and when I was confused he would explain to me his reasons for doing so, after I became familiar with the act he became more proactive and intelligent, it was like an upgrade ......"

"I know if I say YES to him this time, he'll be even smarter next time."

"I think the more approval he gets, the less information and inquiries he has to deliver and the more determined his work will be"

Several participants were able to characterize the process of generating predictive knowledge.

"... In Susan's scenario, I knew that the robot's suggestions for mopping around the stairs were learned from other users, and it made me think that if I shared the knowledge generated by my experience with him I could help more elderly people... "

The explanations of the behavior are too long and repetitive

Some participants complained that the robot took too long to explain before asking the questions that could give the commands, and that some of them were too repetitive.

"The robot was sometimes too talkative, maybe it would be more fruitful to have some differences in the explanations or to inform me in multiple ways, such as through an app or some other screen such as the TV screen when I was watching"

"I would find it annoying if several different predictive behaviors were triggered during the day."

3) Trust of the predictive behavior

Robot's ability to combine the past experience with the predictive behavior plays a crucial role in trust

When asked about the reason for the change in trust of the cleaning decision made by the vacuum robot, most participants attributed the reason to the robot's ability to give new advice based on the strength and the improvement of the shortage from its past performance.

"The fact that he gave me new advice while integrating the points I asked him to improve on the previous time made me feel that he was a solid learner and gave me peace of mind about what he would do next."

Participants can be convinced when perceiving the behavior is data-driven

Participants valued the provided information which indicated that the predictive behavior had already been proven helpful by a certain number of users.

"The fact that he was able to indicate that his behavior had been verified by many cases and proved helpful made me feel that the behavior he performed was reliable"

5.5.2 Evaluation results of Acceptance

The raw data for measuring the acceptance of the predictive behavior included the scores and interview answers from the questionnaire. In general, the questionnaire consists of 3 parts: 1) Participants' general rates of acceptance of the predictive behavior, 2) The recognizability of the design qualities. That is, can participants recognize the qualities from the prototype? 3) The validity of the design qualities. That is, can the qualities help the participant accept the predictive behaviors of the vacuum robot?

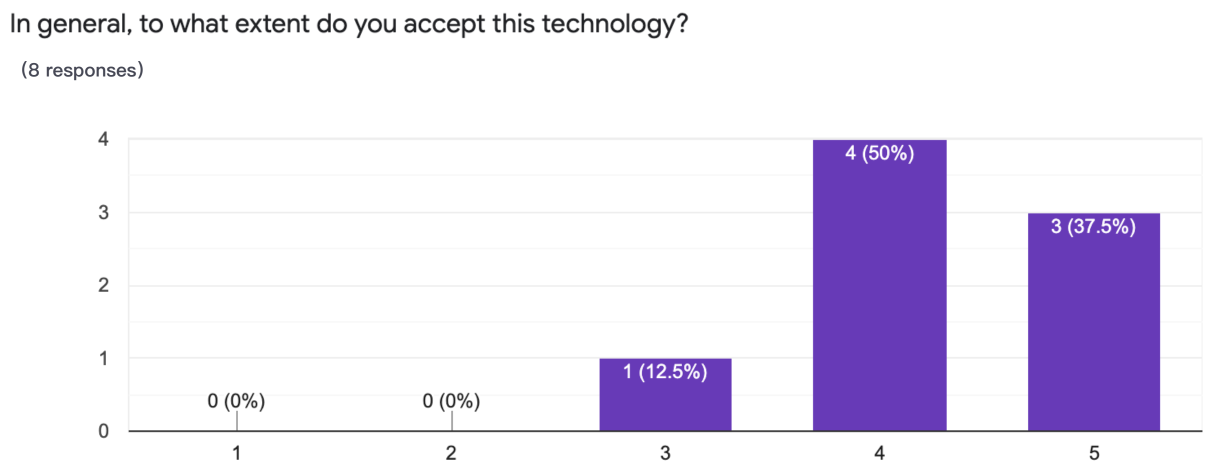


Figure 33: Overall scores of the acceptance of the predicitve behaviors

1) General

Most participants stay positive to embrace the future of things becoming predictive. Yet, they still have some concerns about the risks that this new technology will bring to their life. For example, one of the participants said: "Although I know his behavior can help me in my housework, I kind of feel like I'm losing control of my own life." Some participants expressed little confidence in the accuracy of the predictions: "I feel like my own lifestyle is changing over time and there's not much of a pattern, so I'm not sure the technology is capable of making accurate predictions"

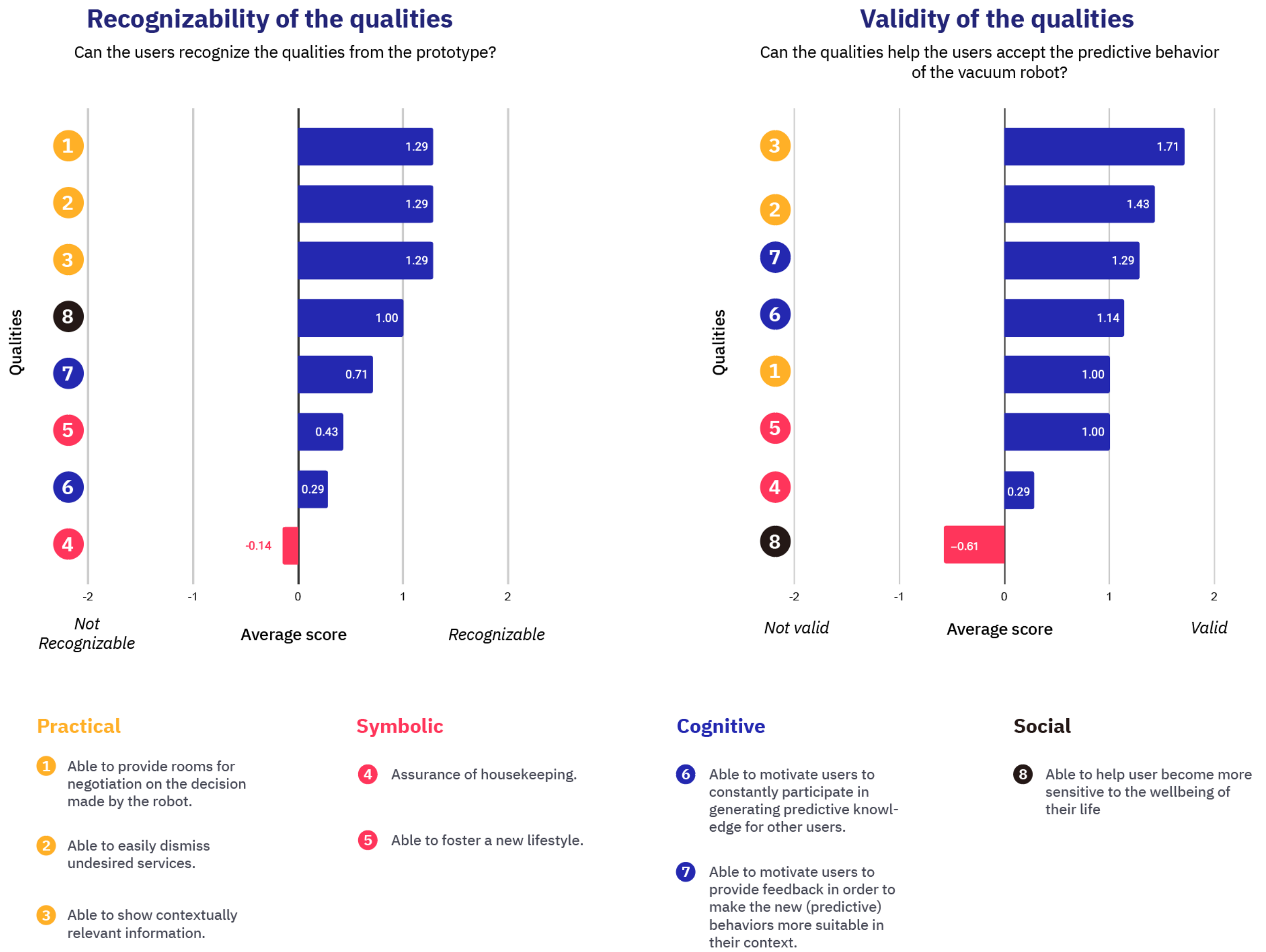


Figure 34: The results of the questionnaire for the design qualities

2) Results of the questionnaire for the design qualities

#1 Most of the qualities are considered capable of helping users to accept the technology

In general, it can be concluded from the scores given to the qualities in the Figure 34 that most of the qualities were considered to help participants better accept predictive behavior. However, some qualities were found to need refinement or were not directly understood during the tests and needed further explanation by the researcher. These will be explained in detail in #4 and #5 respectively.

#2 Qualities from the practical dimension are most likely to be observed from the prototype and considered to be the most valid

Based on the results, it is not difficult to find that the most recognizable qualities when interacting with the prototype were the qualities from the practical dimension. The ability of the robot to provide contextually relevant information was considered to be the most helpful quality of the predictive behavior:

"I felt that he was making these decisions based on the facts around me, and this makes me think that the predictive behavior is understandable and acceptable".

However, as mentioned above, providing too much background information or too general information can be annoying and ineffective for users. Therefore, more research is required in the future to figure out how the predicting robot can better provide contextual information and in what way it can be presented.

#3 Robot's ability to motivate users to provide information was considered important but was missing from the prototype.

As shown in the Figure 34, quality 6&7 did not receive high scores in recognizability but instead ranked high in validity. Participants' motivations of providing feedback and donating their data were weak when interacting with the prototype, but robots having these qualities are considered important for the acceptance of predictive behavior. Because of time limitations and the research focus of this project is not on how to motivate users to provide feedback, the prototype was created without much in-depth detailing on how to motivate users, which instead led participants to emphasize the importance of these qualities after experiencing the prototype. They also gave suggestions for Quality 6:

"It would be more engaging for me to know what impact I'm making by contributing this information"

"It could be more explicit about what information I'm going to share, like what patterns of housework he has summarized from our cooperation, and that would be fun!"

#4 No comparison

Quality 8 proposes that the users may become more sensitive to the details of their life as they perceive the predictions are coming from other users and will learn from others. However, this quality received negative feedback in the test. In the test, the robot suggested mopping the floor due to high humidity and told the user how he generated this decision with the information that many users choose to mop at this time of the day to keep their floors dry. Several participants expressed their dislike of this:

"Well, I understand that he told me this information to make me feel that his decision was reliable and reasonable, but it also made me feel defensive. Why should I do the same just like others?"

"It's like he has his own social circle with other robots, and I know he learns a lot from there, but I feel offended if he's always comparing my situation to others"

Thus, when a robot is trying to prove that its predictive behavior is reasonable, it is not a good idea to compare the individual's situation with other users, even though the users know that the information is anonymous. Therefore, in the social aspect, the robot should try to minimize comparisons, and Quality 8 is adjusted and modified as: **No comparison**

#5 Predicting robots as a symbol of assurance of housekeeping covers too broadly and vaguely

As shown in the Figure 34, Quality 4 received low scores in both recognizability and validity, and most participants did not even perceive the vacuum robot as an assurance of housekeeping from the prototype. This is because most of the participants thought that the term "housekeeping" was too broad and general. They still insisted that no matter how intelligent and predictive a vacuum robot becomes, it is still a sweeper and the scope of its work has not been extended to the stage where it can act as a housekeeper.

"If you ask me if he has done a better cleaning job, I totally agree. But if you ask me if he has been able to achieve the same feeling as a housekeeper, I think he's still by nature a sweeper."

"Mostly, I don't expect too much from him, just that he can sweep the floor, so I don't expect him to do anything else."

Besides, when discussing this quality, they also argue that the predictive behavior should relate to the individual's knowledge of what the vacuum robot is supposed to do.

"I know that when this technology turns out to be a reality, he will give me a lot of surprises, and even know how to do the cleaning better than I do, but his behavior should still be in line with my key expectations of this product, I mean, like, saving my time on cleaning the floor. "

So quality 4 could be improved as follows: **Be a surprise but still relate to the individual's knowledge of what the robot should do.**

>5.6 Discussion

The loop of co-performance can enhance the transparency of the predictive behavior

From the test results in Figure 32, it can be seen that the participants' understandability and trust of the predictive behavior are in an increasing trend after 5 rounds of interaction, and in this process, they can identify why the prediction happens and how it is being generated. Besides, participants found it reliable and trustworthy in the test as the predicting vacuum robot can integrate users' instructions to improve their predictions and suggestions. Therefore, it can be stated that users can enhance their understanding of the predictive behavior through the loop of co-performance, and in this process, the details of each predictive behavior are being adjusted to best fit their context. The transparency of the predictive behavior is thus improved.

The predictive behaviors of the vacuum robot are acceptable and most of the design qualities are valid for improving the acceptance

In the test, most of the participants held an accepting attitude towards predicting the vacuum robot. And through in-depth interviews with the results of the questionnaire, they agreed that most of the proposed design qualities integrating into the test helped them to accept the predictive behavior of the vacuum robot. However, two of the qualities needed to be refined and modified. They were modified as follows: **1) Quality 4: Be a surprise but still relate to the individual's knowledge of what the robot should do; 2) Quality 8 : No comparison**

The prototype is able to serve as a speculative trigger to open up the discussion about the future where the things become predictive

Through Wizard of OZ, the prototype stimulated debate and discussion between the participant and the researcher about the future of the everyday product, and the most fruitful of which was the discussion about what qualities should the predicting things have. During the discussion, some participants said that this speculative test helped them imagine the predicting thing more clear and accessible, which no longer made them perceive it as a surrealistic thing, and their fear of this relatively advanced technology was relieved.

"I think the fear that people used to have about the development of robotic things was probably that they would worry that these things would completely replace humans. For example, most typically, humans are afraid that artificial intelligence will completely replace their careers and jobs. But through the test, I would think that in the future people and robots are more like in a closer and more cooperative relationship, and I can still see the value of humans and their irreplaceability."

Designers as facilitators of collaboration between humans and robots

The interview eventually led to discussions and reflections on the shifting roles of designers and developers when designing the predicting things in the future. From the prototype, it is not hard to notice that, in the future, the process of defining products——what the products should do and how to do, has shifted from the stage of the design process to the stage where users use the product. So in this case, what will be the changes in the role of designers? During discussions with the participants, some of them thought that the designer should be the one to help the user set up a proper expectation of the robot's capabilities. Admittedly, robots empowered with artificial intelligence have great potential, but there are still limitations to what they can accomplish. The designer, therefore, has the responsibility to help the user understand what the predicting robot can do and how well it can do.

In addition, when robots are equipped with the abilities of self-awareness and self-determination, their role changes from the commands followers to a collaborator on equal footing with humans. At that time, humans are no longer in the state of outputting one-way commands to robots, but humans and robots are in a state of bidirectional communication, or even bidirectional negotiation and compromise. By then, the focus of designers and product developers will be extended to how to guide the users and the predicting robots to form a well-coordinated partnership and how to lead this partnership to co-create reliable and meaningful knowledge. Therefore, this project proposes the view: when the connected things become predictive, one of the roles of the designer is to facilitate the collaboration between humans and robots.

5.7 Conclusion

About 2 propositions

The results of the evaluation proved that the 2 propositions proposed in Session 4.3 are valid to improve the transparency and the acceptance of the predictive behaviors. Besides, the evaluation also came up with a modified version of the design qualities for the acceptance of the predicting vacuum robot :

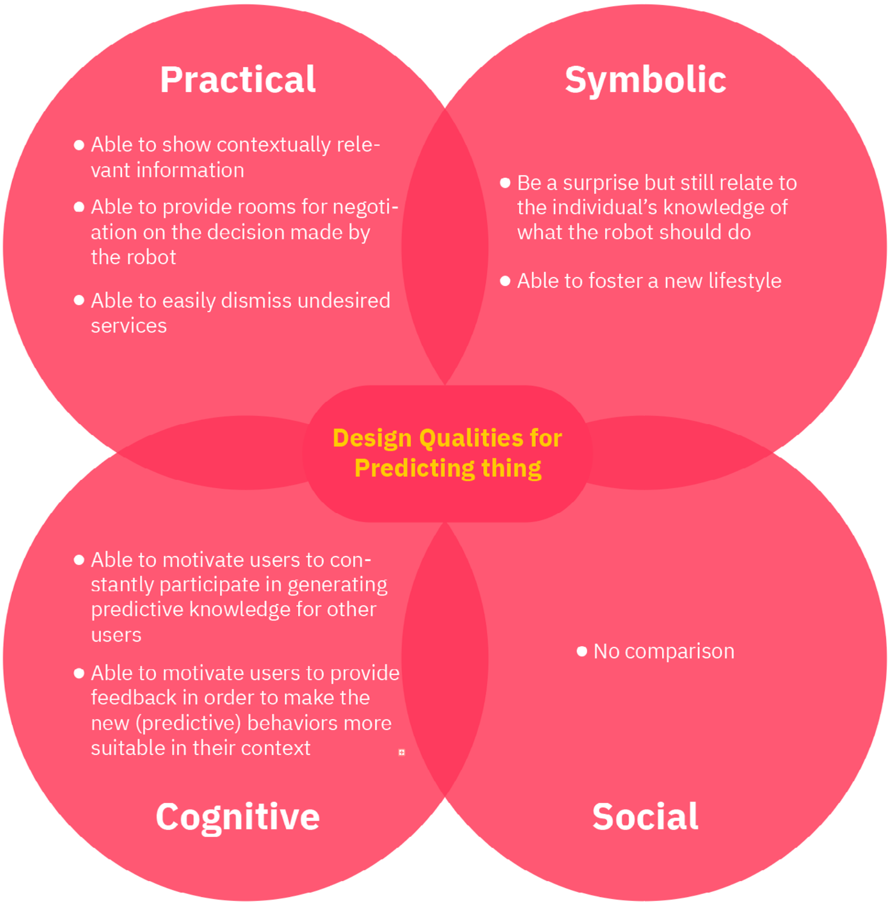
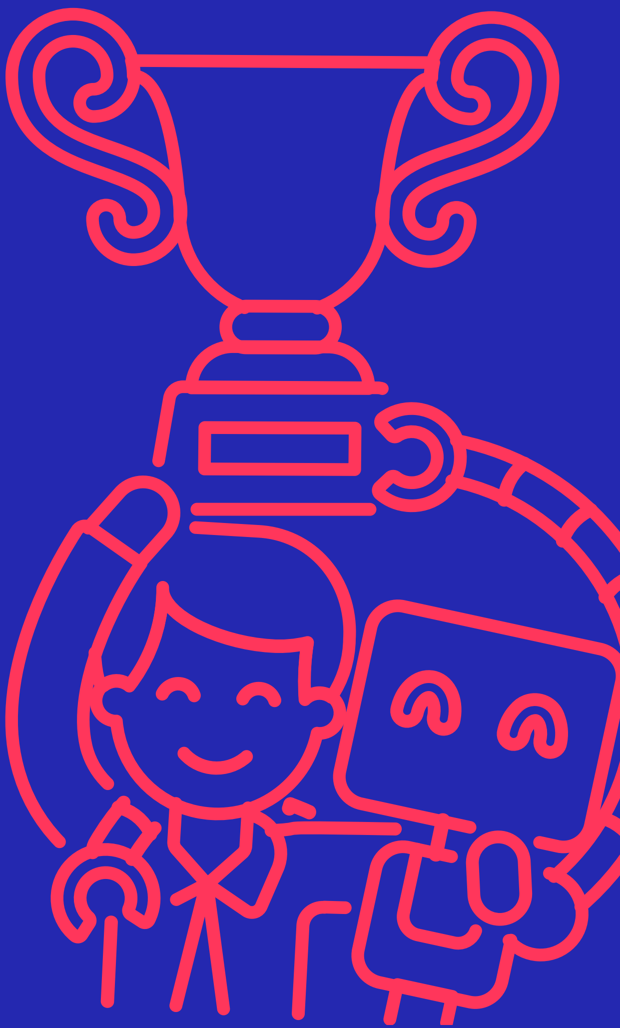


Figure 35:The modified design qualities for acceptance after the evaluation

Designers as facilitators of human-robot collaboration

The evaluation led to discussions among the participants with design backgrounds about the changing role of the designers when the things become predictive. The key opinion that can be concluded from the discussions is that when the connected things become predictive, one of the roles of the designer is to facilitate the collaboration between humans and robots. The designers here are the ones who help to bring in the background knowledge and the patterns of the predictive relation, and indicate the ways for humans and robots to co-perform reliable and meaningful daily practice in their partnership.

Chapter overview



This chapter proposed a guidebook as one of the ways to facilitate the collaboration between humans and predicting robots, integrating the main insights and results of this project.

Chapter 6

A guidebook for human-robot collaboration

6.1 Guidebook for human-robot collaboration

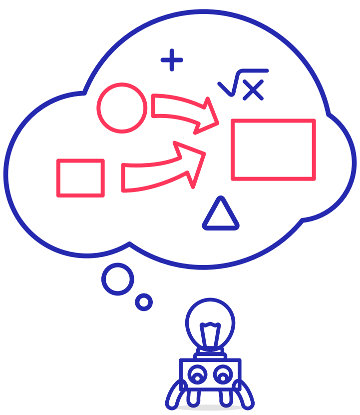
Designers as facilitators of human-robot collaboration

When the connected things start to learn from the connected users in the cloud and predict outcomes, they are equipped with the abilities of self-awareness and self-determination. In this circumstance, the role of the predicting things shifts from the commands follower to the collaborator on equal footing with human beings. At that time, humans are no longer in the state of outputting one-way commands to robots, but humans and robots are in a state of bidirectional communication, or even bidirectional negotiation and compromise. This will also lead to the changing roles of the designers and product developers to extend their focus on how to guide the users and the predicting robots to form a well-coordinated partnership and how to lead this partnership to co-create reliable and meaningful knowledge. Based on this viewpoint, this project will attempt to promote human-robot collaboration in the form of a guidebook with the two proposed propositions as the main content.

Why choose a guidebook as a way to facilitate collaboration?

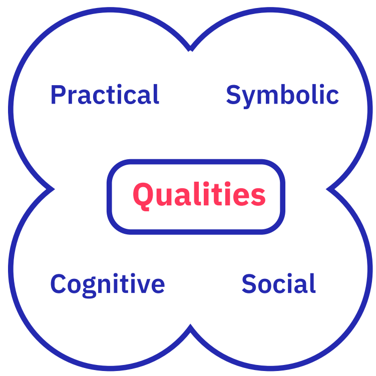
As the starting point of the usage of a product, an instruction manual has the role of guiding the user to have an overview of the product. However, in the traditional manual, the focus is mainly on the details of how to install and operate the products and introducing the features to the user. When the things are able to form their behaviors in everyday practice, what the products can achieve and what they are going to do are defined together with the users during the usage. In other words, designers may not fully know the detailed features of the product in the design process. Thus, there is an urge for designers to come up with a new form of instruction for their product that guides the collaboration between humans and objects instead of describing the features of the products. In this project, taking the predicting vacuum robot as an example, the guidebook will serve as a toolkit for robots to have a self-introduction with a perspective of humans and objects being on an equal footing, and bring in the knowledge of how to treat each other in their partnership.

6.1.1 Integrating the 2 propositions into the guidebook



Wireframe of generating the predictive knowledge

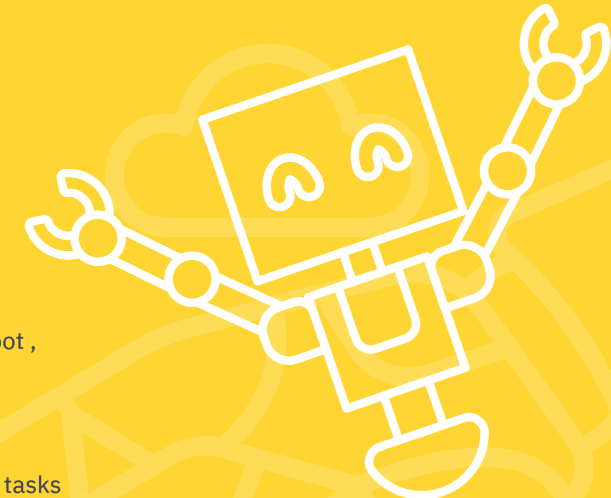
- To open up the “technology black box” for human to understand the working of predictive knowledge



Design qualities for predicting vacuum robot

- To draw a picture for human to learn their roles in the predictive relationship and what qualities will the predicting vacuum robot have in their relationship.
- To guide human how to collaborate with the predicting robot.

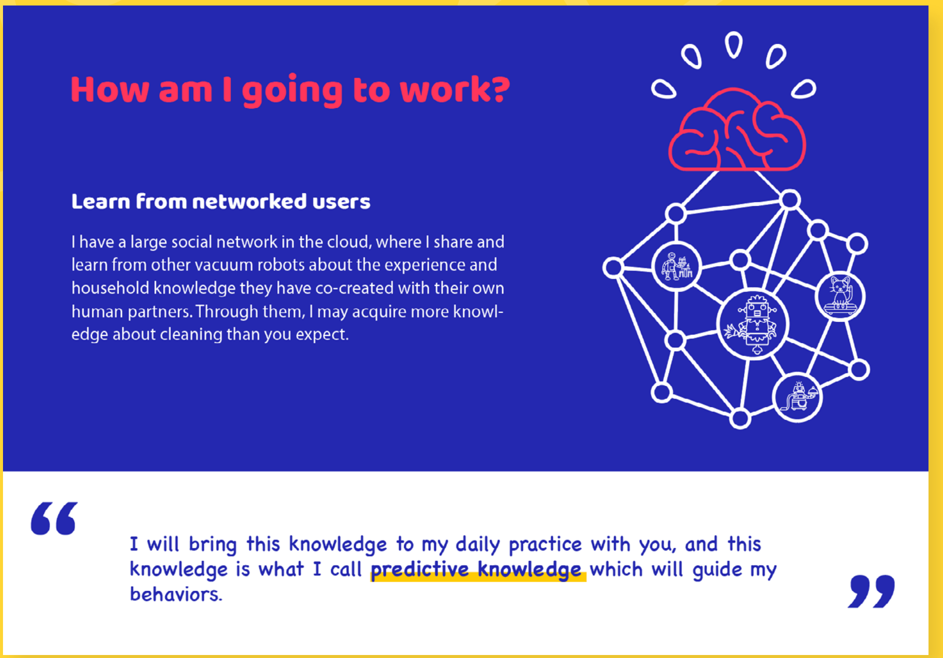
Guidebook



For human to collaborate with the predicting vacuum robot

The guidebook is a self-introduction from a predicting vacuum robot , which consists of 4 parts:

- The working of a predicting vacuum robot
- Human's roles in the collaboration
- Tips for human to work with the predicting vacuum robot
- How the prediciting vacuum robot will take the initiative of the tasks

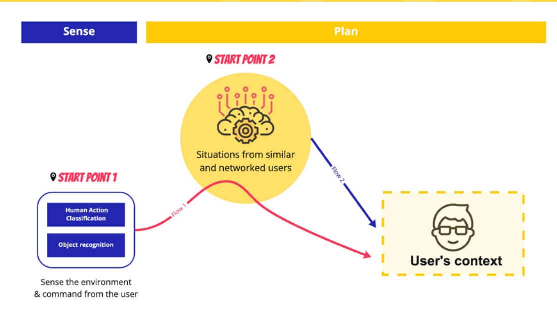


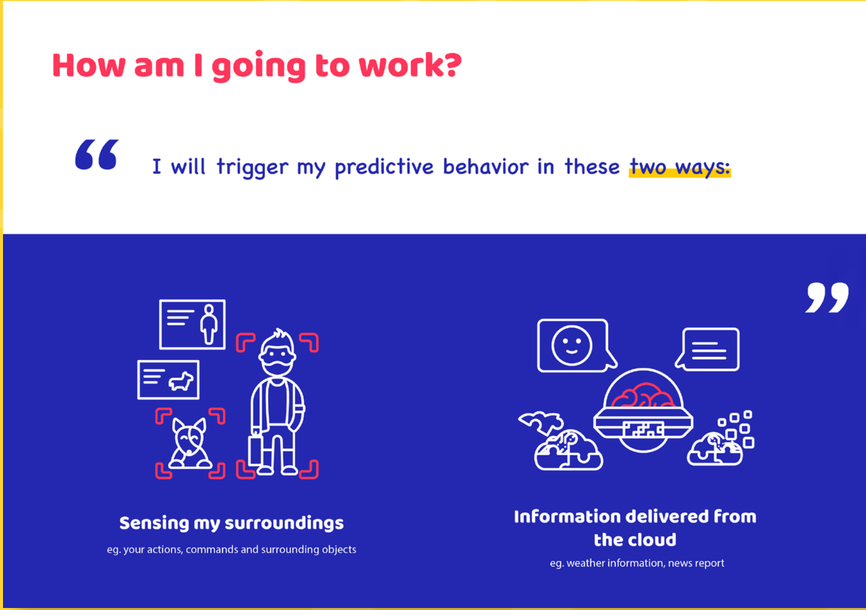
> **Page 1**

Introducing the robot's predictive knowledge is learn from networked users

> Page 2

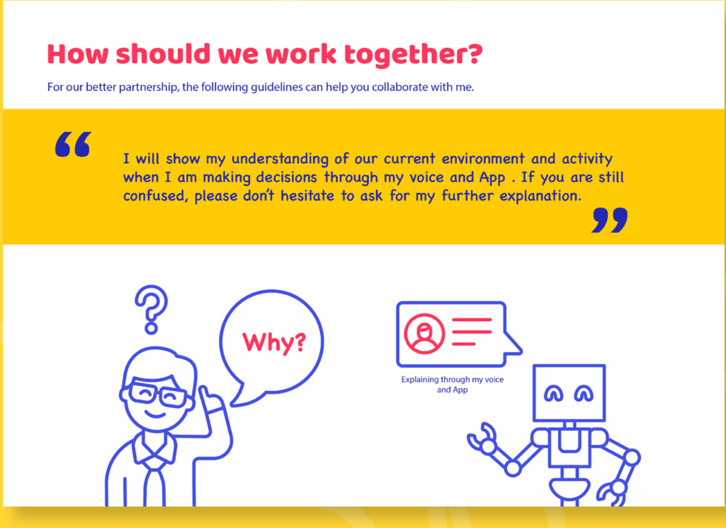
Introducing how the robot trigger the predictive knowledge





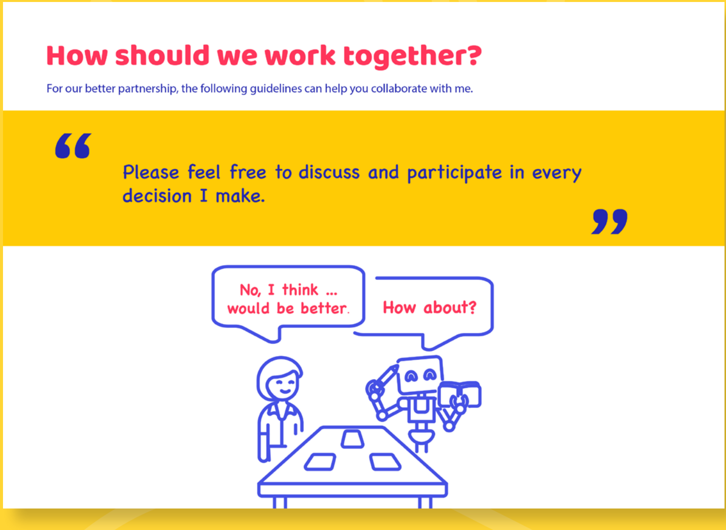
> Page 3

Introducing human's role the relationship



> Page 4

3. Able to show contextually relevant information



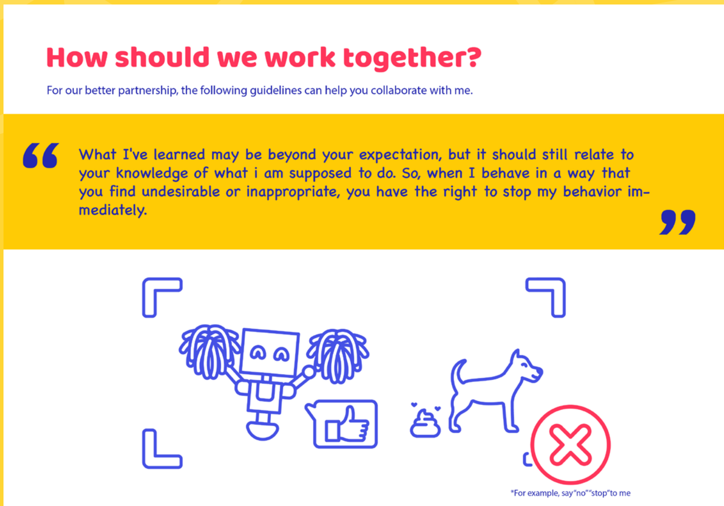
> Page 5

1. Able to provide rooms for negotiation on the decision made by the robot

> Page 6

4. Be a surprise but still relate to the individual's knowledge of what the robot should do

2. Able to foster a new lifestyle



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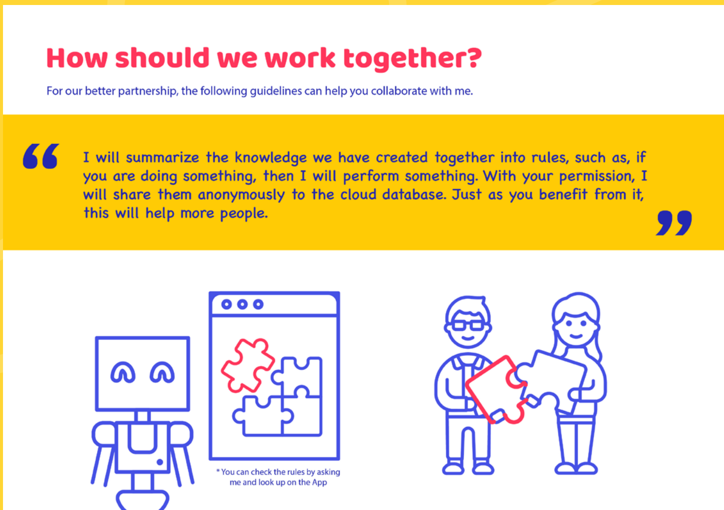
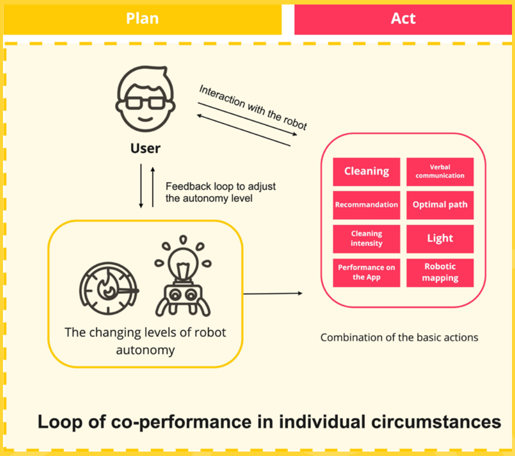
6. Able to motivate users to constantly participate in generating predictive knowledge for other users



> **Page 8**

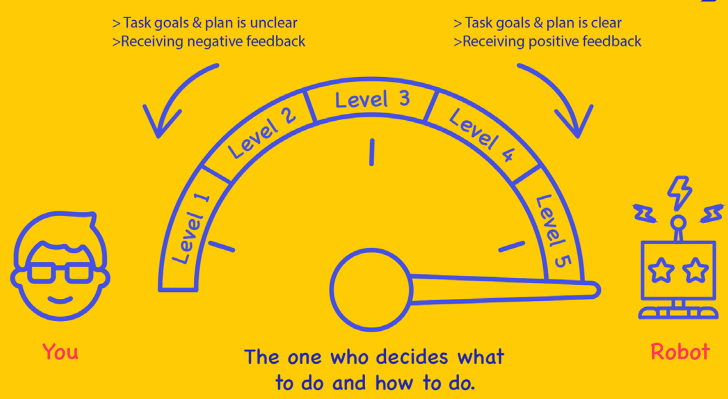
Introducing the changing autonomy level of the robot



How will I take the initiative of the task?

Each of your feedback will influence my initiative of the tasks

“To minimize your effort, my initiative on the task increases when I receive positive feedback from you; on the contrary, when my goals for the task are unclear or your response to my performance is negative, you will have more control over the work.”



My initiative Levels

Level 1 — **Manual**
You will have complete control of me

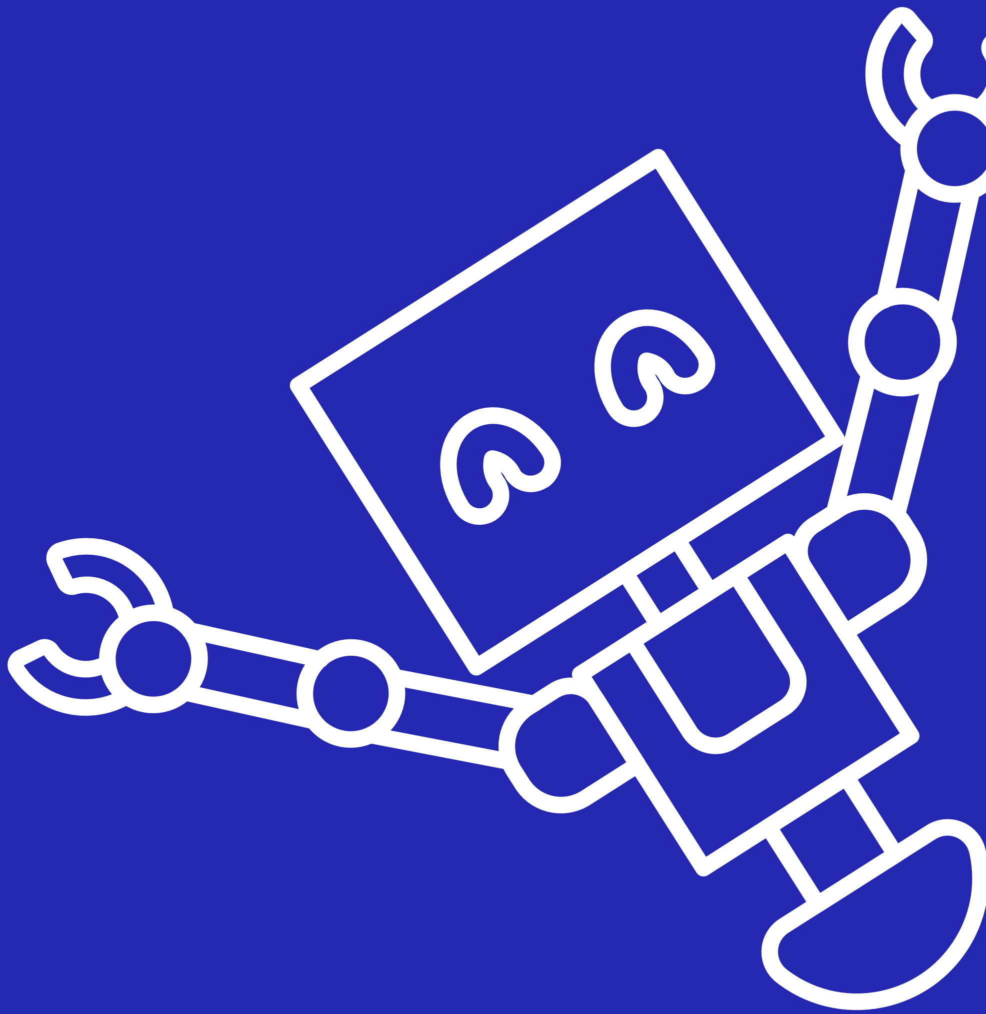
Level 2 — **Batch Processing**
You set up the plans and actions for me to perform.

Level 3 — **Decision Support**
I will provide choices of plans and action for you to choose

Level 4 — **Supervisory Control**
I will ask for your permission and perform the tasks autonomously

Level 5 — **Full autonomy**
I will autonomously go for the task.

* You can check the levels by asking me or look up the lights on my body and on the App



Chapter 7

Project conclusion, Limitation & Recommendation

7.1 Project conclusion

7.1.1 Addressing the research question

How to design transparent and acceptable predictive relations for the things that predict?

The purpose of this project is to explore the predictive relations and study the transparency and the acceptance of the predictive behavior. In answering the initial research question, this project proposed 2 propositions for transparency and acceptance respectively by combining the insights generated from the case study of XiaoMi's vacuum robot and the creative session of envisioning the working of predicting vacuum robots. The 2 propositions are evaluated through the method of 'Wizard-of-oz' and proved valid by combining the results of quantitative and qualitative research.

Transparency

Proposition: The loop of co-performance in the proposed wireframe, will result in the changing autonomy level and help to increase the understandability and trust of the predictive behavior.

This project proposes a wireframe of generating predictive behavior, aiming at revealing how the predictive behaviors are being triggered in human's daily life and how the predictive knowledge is being developed. The proposed wireframe also indicates a loop of co-performance where humans and robots will learn and adapt the behavior of each other and the labor distribution between humans and robots will be dynamically changed throughout the interplay. Also, since the interplay reveals the learning process, the reasoning and the generating process of the predictive behavior can be explained in the loop of co-performance, and thus enhance the transparency of predictive behavior.

Acceptance

Proposition: The domestication qualities indicate how the predictive knowledge of the vacuum robot is being implemented and accepted in our life.

Based on the domestication theory (Søraa et al., 2021; Berker, 2005; Lie and Sørensen, 1996), this project also identifies and verifies the design qualities for the acceptance of the predicting vacuum robot. 8 qualities are divided into 4 dimensions and summarized as follows:

<u>Practical domestication</u>

1. Able to provide rooms for negotiation on the decision made by the robot.
2. Able to easily dismiss undesired services.
3. Able to show contextually relevant information.

<u>Symbolic domestication</u>

4. Be a surprise but still relate to the individual's knowledge of what the robot should do
5. Able to foster a new lifestyle.

<u>Cognitive dimension</u>

6. Able to motivate users to constantly participate in generating predictive knowledge for other users.
7. Able to motivate users to provide feedback in order to make the new (predictive) behaviors more suitable in their context.

<u>Social dimension</u>

8. No comparison

What will be the role of the designer when things become predictive?

Designers as facilitators of human-robot collaboration

By engaging and evaluating the predictive relations through wizard of oz, the interview from the evaluation test led to fruitful discussions among the participants with design backgrounds about the changing role of the designers when the things become predictive. The key opinion that can be concluded from the discussions is that when the connected things become predictive, one of the roles of the designer is to facilitate the collaboration between humans and robots. When the connected things start to learn from the connected users in the cloud and predict outcomes, they are equipped with the abilities of self-awareness and self-determination. In this circumstance, the role of the predicting things shifts from the commands follower to the collaborator on equal footing with human beings in everyday practice. The designers can be the ones who help to bring in the background knowledge and the patterns of the predictive relation, and indicate the ways for humans and robots to co-perform reliable and meaningful daily practice in their partnership.

7.2 Limitation

7.2.1 Limitation of the design qualities

Due to the scope set up at the beginning of this project, the design qualities for acceptance proposed in this project are mainly based on the research results of predicting vacuum robots, and cannot be generalized to all predicting objects. Therefore, a more universal design qualities for the acceptance of predicting things need to be summarized in patterns from more types of 'smart things'.

7.2.2 Limitation in the prototype & evaluation

Since this project was in the lockdown period of 'Covid-19' when the evaluation was conducted, the prototype was created and tested only on the online platform. The participants were not in the original context of use but a virtual context. Therefore, in the real situation, many aspects of the interaction between the participants and the prototype were missing in the test, such as emotions and gestures.

7.2.3 Limitation in the guidebook

Due to time constraints, the guidebook was not evaluated in this project, and thus, the opinions from the users' side are missing.

7.3 Recommendation for further research

7.3.1 The ways for facilitating the human-robot collaboration

This article presents the idea that when the connected things become predictive, one of the roles of the designer is to facilitate the collaboration between humans and robots. In this regard, the article explores the role of the designer to facilitate the collaboration between humans and robots in the form of a guidebook. However, there is still much room for more systematic exploration, such as designing a systematic pre-sales and after-sales service system to facilitate collaboration.

7.3.2 About the autonomy level

This article presents a wireframe that explores how predictive behavior can be triggered and developed. It specifies that predictive behavior defines its own initial autonomy level by combining knowledge from the cloud and understanding of the user's past experiences. However, this paper does not dive deeply into how this initial autonomy level will be defined. In the result of the evaluation, it can be seen that different users have various expectations and acceptance of the autonomy level for different behaviors. This leads to a more in-depth research question: How to determine the best autonomy level of predictive behavior when it first takes place in the user's context? What variables would influence the initial autonomy levels ?

Personal reflection

As a research-based topic, this project is different from previous design projects I have experienced——identifying problems and coming up with achievable or near-future achievable design solutions. This project is more about envisioning and hypothesizing about the future.

What I find most interesting and fascinating in this project is finding clues from existing smart objects to formulate propositions about the future. I first investigated the working and the context of existing vacuum robots through literature review and observation and made a proposition about the working logic and the qualities of the predicting vacuum robot by combining the results of the creative session.

However, the biggest difficulty in this project, in my opinion, is the verification of these propositions. This is partly due to the fact that during the 'covid-19' period, testing could only be done online. But I think the difficulty is more due to the inability to fully implement or simulate the predictive behaviors. Therefore, in testing, more often than not, the researcher and the participants are required to create such scenarios through their imagination, which may lead to the gaps of the imagination between researcher and participants. For example, the researcher intended to imagine and simulate a vacuum robot that could have the same intelligence and consciousness as humans through the form of wizard-of-oz, while the participant might be limited by his understanding of current AI technology and confidence in the development of this technology, and could not treat the vacuum robot acted by the researcher with the same level of intelligence, thus affecting his behavior when interacting with the 'predicting thing' in the evaluation test. Therefore, some participants would say: "I wanted to tell him that I would like him to start cleaning after I finished the laundry, but I wasn't sure if he would understand and implement this behavior". Inevitably, some effort was spent on defining and scoping out how smart the predicting vacuum robot is during the testing process. Of course, everything has two sides, the ambiguity also triggers a variety of interpretations and ideas, and it is obvious from the interview results that each participant has various opinions and insights about the predictive behavior of the prototype, which is also the charm of this project.

One of the reasons that drove me to start this project was that I wanted to expand the boundaries of my abilities and practice my research skills. During my studies in undergraduate and graduate school, most of the time I was focused on improving my design skills. I am grateful to have the opportunity to approach this research-oriented topic near the end of my graduate studies, and to realize my original purpose in choosing to study abroad at TU Delft——a school specializing in research. Admittedly, it was also a challenge for me. As a person who strives to have the most control over things and expects things to go as planned, choosing a research-based project means pushing me to deal with the unknowns and changing strategies and approaches from time to time, as well as being in a continuous process of self-criticism. This would be a confusing and anxiety-inducing experience for me. Fortunately, I had a super responsible supervisory team that supported me every week throughout the project. I would like to express my special thanks to Nazli for helping me to get to the point of the problem, clarify the problems and research ideas when I was lost and stuck, and to Iskander for giving me the opportunity to try out the project and being responsive and supportive to my worries as well as guiding me through the project.

When I first met this research topic in Iskander's workshop, he said that this topic is about designing for "unknown unknowns". I think, through this project, I not only got some understanding of how to design for "unknown unknowns", but also learned how to deal with myself when facing unknown unknowns, and I think this will benefit me for long.

Reference

A

Amershi, S., Weld, D., Vorvoreanu, M., Fourney, A., Nushi, B., Collisson, P., Suh, J., Iqbal, S., Bennett, P. N., Inkpen, K., Teevan, J., Kikin-Gil, R., & Horvitz, E. (2019). Guidelines for Human-AI Interaction. Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems. Published. https://doi.org/10.1145/3290605.3300233

B

Beer, J. M., Fisk, A. D., & Rogers, W. A. (2014). Toward a Framework for Levels of Robot Autonomy in Human-Robot Interaction. Journal of Human-Robot Interaction, 3(2), 74. https://doi.org/10.5898/jhri.3.2.beer

Berker, T., 2005. Domestication of Media and Technology. McGraw-Hill Education, UK.

Blakemore, S. J., & Decety, J. (2001). From the perception of action to the understanding of intention. Nature Reviews Neuroscience, 2(8), 561–567. https://doi.org/10.1038/35086023

C

Chien, S.-Y., Lewis, M., Semnani-Azad, Z. & Sycara, K. An Empirical Model of Cultural Factors on Trust in Automation. Proc Hum Factors Ergonomics Soc Annu Meet 58, 859–863 (2014).

D

Davis, F. D. (1989). Perceived Usefulness, Perceived Ease of Use, and User Acceptance of Information Technology. MIS Quarterly, 13(3), 319. https://doi.org/10.2307/249008

F

Felzmann, H., Fosch-Villaronga, E., Lutz, C., & Tamò-Larrieux, A. (2020). Towards Transparency by Design for Artificial Intelligence. Science and Engineering Ethics, 26(6), 3333–3361. https://doi.org/10.1007/s11948-020-00276-4

Floridi L, Cowls J, Beltrametti M, Chatila R, Chazerand P, Dignum V, Schafer B (2018) AI4People—An ethical framework for a good AI society: opportunities, risks, principles, and recommendations. Mind Mach 28(4):689–707

Forlizzi, J. & DiSalvo, C. Service robots in the domestic environment: a study of the roomba vacuum in the home. 258–265 (2006) doi:10.1145/1121241.1121286.

Franklin, S., & Graesser, A. (1996). Is it an agent, or just a program? A taxonomy for autonomous agents. In Proceedings of the Third International Workshop on Agent Theories, Architectures, and Languages, Intelligent Agents, 21-35. Budapest Hungary. doi: 10.1007/BFb0013570

H

Huang, H.-M, (2004). Autonomy levels for unmanned systems (ALFUS) framework volume I: Terminology version 1.1. In Proceedings of the National Institute of Standards and Technology (NISTSP), Gaithersburg, MD.

I

ITU. (2005, November). The Internet of Things. https://www.itu.int/net/wsis/tunis/newsroom/stats/The-Internet-of-Things-2005.pdf

K

Kuijer, L., & Giaccardi, E. (2018). Co-performance. Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems. Published. https://doi.org/10.1145/3173574.3173699

L

Lie, M., Sørensen, K.H., 1996. Making technologies our own? Domesticating technology into everyday life. In: Ling, R., Pedersen, P.E. (Eds.), Mobile Communications: Renegotiation of the Social Sphere. Springer, pp. 1–30.

M

Murphy, R. (2000). Introduction to AI Robotics (pp. 1-40). Cambridge, MA: The MIT Press.
Rose, K., Eldridge, S., & Chapin, L. (2015). The internet of things: An overview. The internet society (ISOC), 80, 1-50.

Reference

R

Rosen, C. A. & Nilsson, N. J (1966). Application Of Intelligent Automata to Reconnaissance. Technical Report. Menlo Park, CA: Stanford Research Institute.

Rowland, C., Goodman, E., Charlier, M., Light, A., & Lui, A. (2015). Designing connected products: UX for the consumer Internet of Things. " O'Reilly Media, Inc.".

S

Sanders, E. B. (2001, September). Virtuosos of the experience domain. In Proceedings of the 2001 IDSA education conference.

Smit, I. (2021, January 5). Designing predictive relations in more-than-human partnerships – Cities of Things. Cities of Things. https://cityofthings.nl/2021/01/05/designing-predictive-relations-in-more-than-human-partnerships/

Søraa, R. A., Nyvoll, P., Tøndel, G., Fosch-Villaronga, E. & Serrano, J. A. The social dimension of domesticating technology: Interactions between older adults, caregivers, and robots in the home. Technol Forecast Soc 167, 120678 (2021).

T

Thrun, S. (2004). Toward a framework for human-robot interaction. Human-Computer Interaction, 19(1-2), 9-24. doi: 10.1207/s15327051hci1901&2_2

W

Wachter S, Mittelstadt B, Floridi L (2017) Why a right to explanation of automated decision-making does not exist in the general data protection regulation. Int Data Privacy Law 7(2):76–99

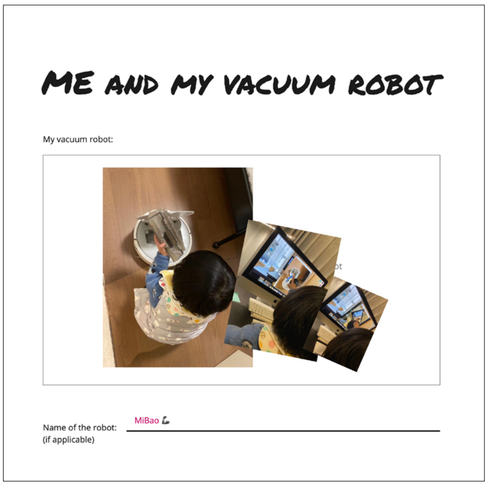
World Economic Forum. (2015). Industrial Internet of Things: Unleashing the Potential of Connected Products and Services. http://www3.weforum.org/docs/WEFUSA_IndustrialInternet_Report2015.pdf

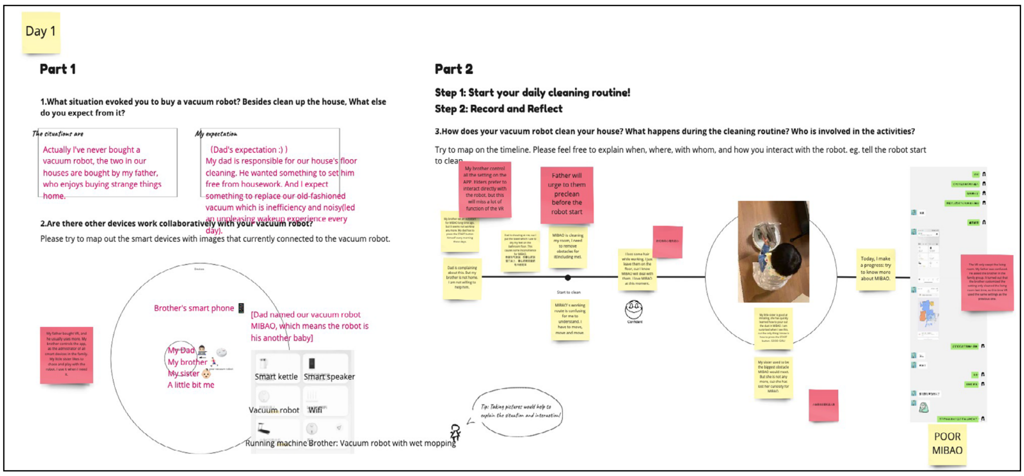
Y

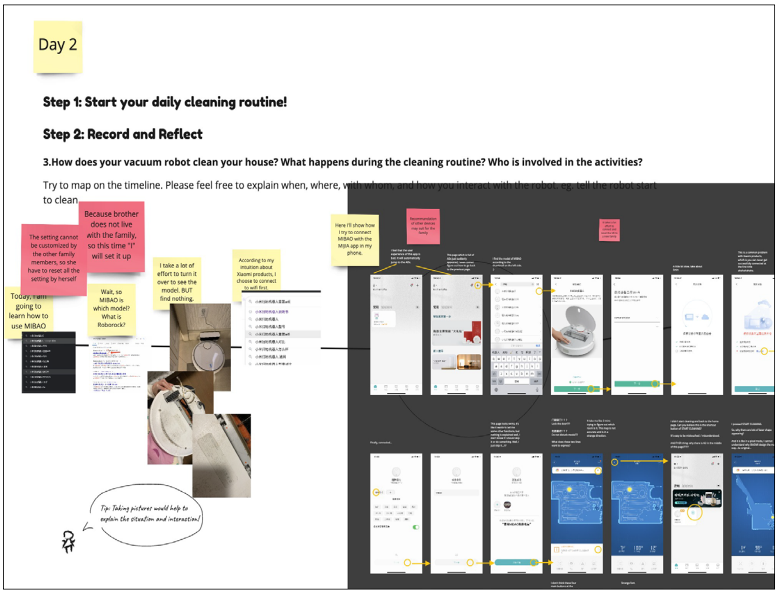
Yu, Z., Kim, S., Mallipeddi, R. & Lee, M. Human Intention Understanding Based on Object Affordance and Action Classification. 2015 Int Jt Conf Neural Networks Ijcnn 1–6 (2015) doi:10.1109/ijcnn.2015.7280587.

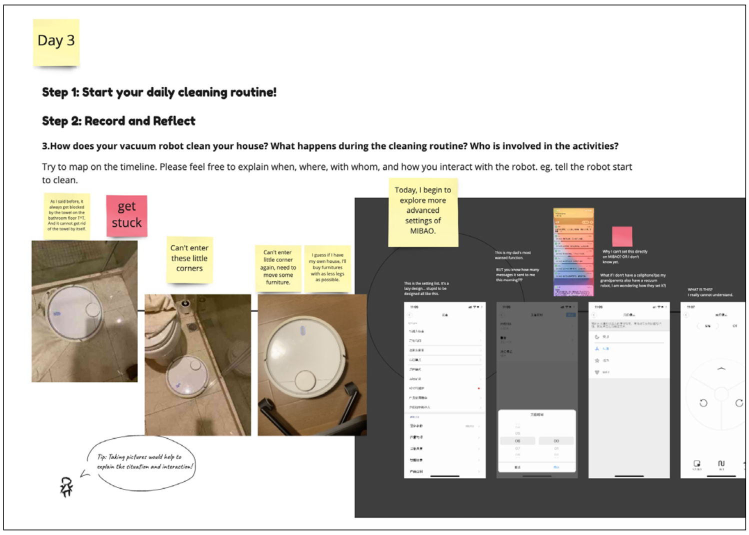
Appendix

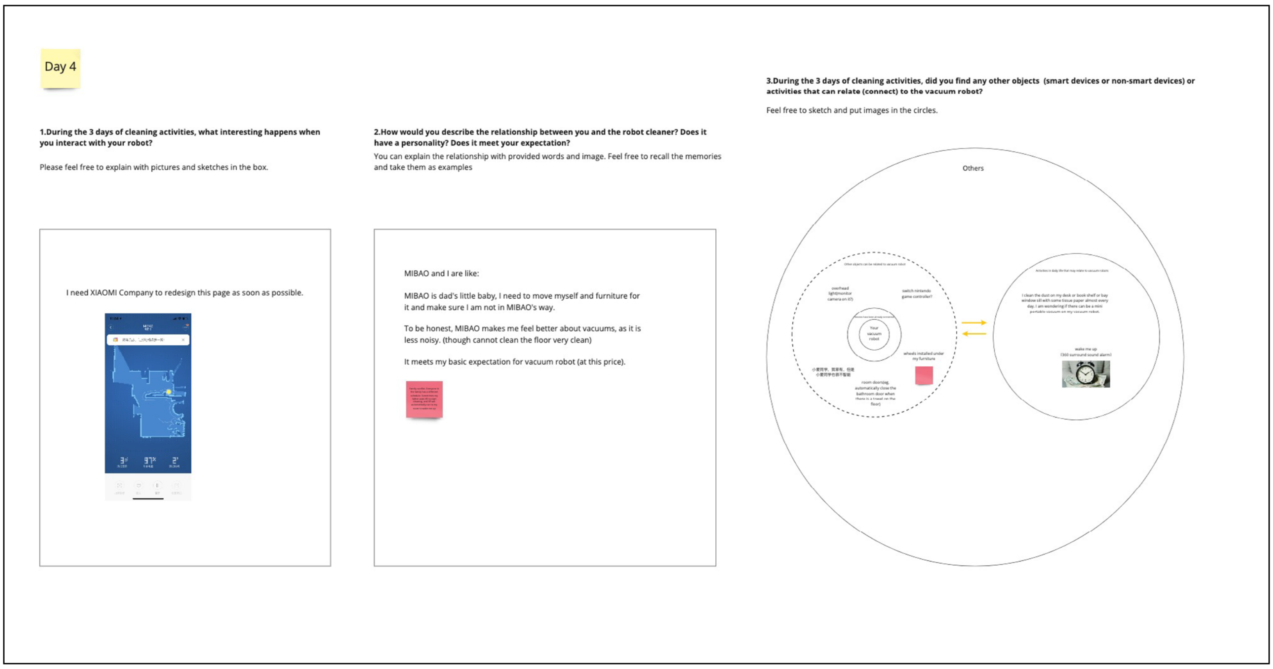
> Appendix A - Diary booklet of participant a



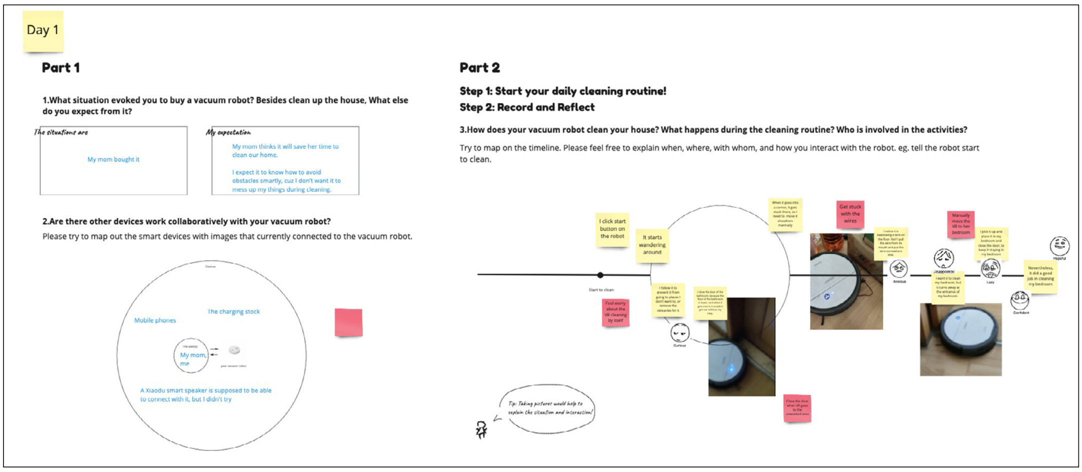


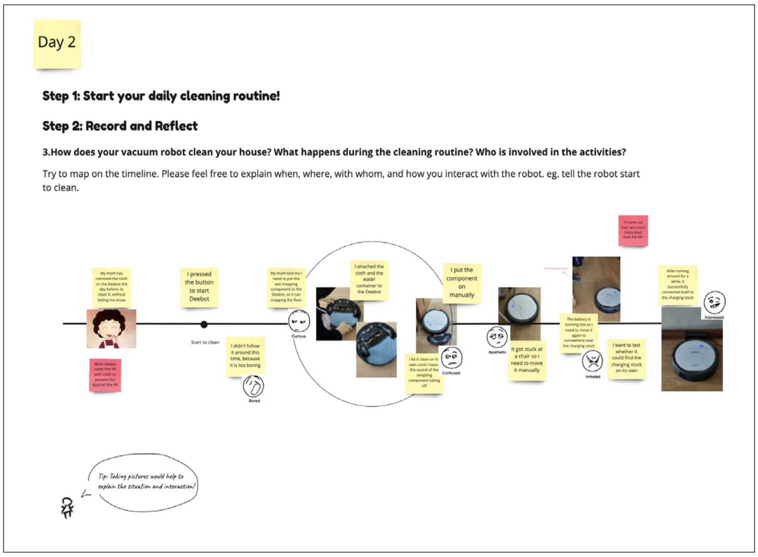


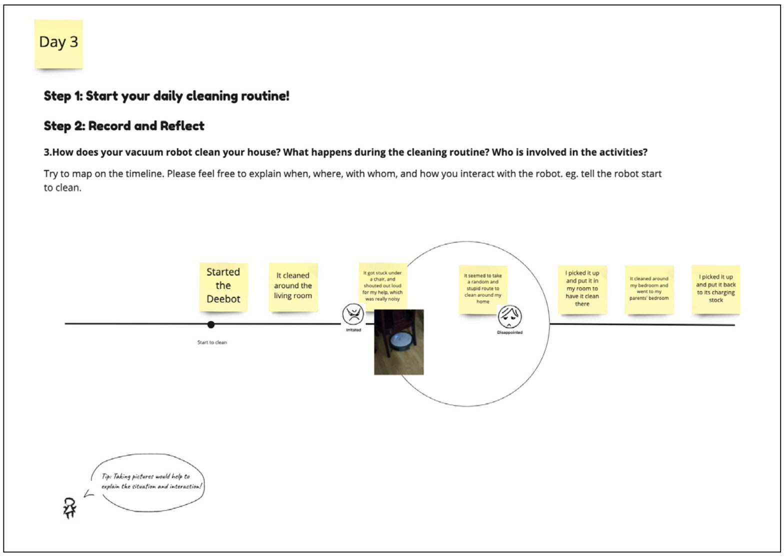


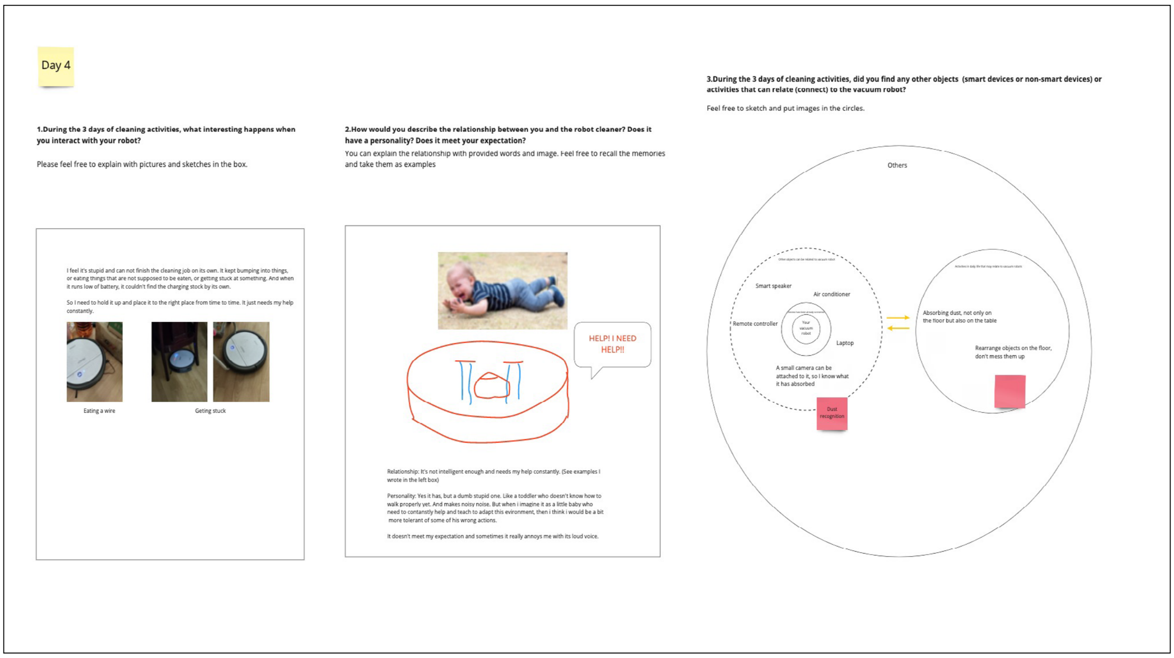


> Appendix A - Diary booklet of participant b

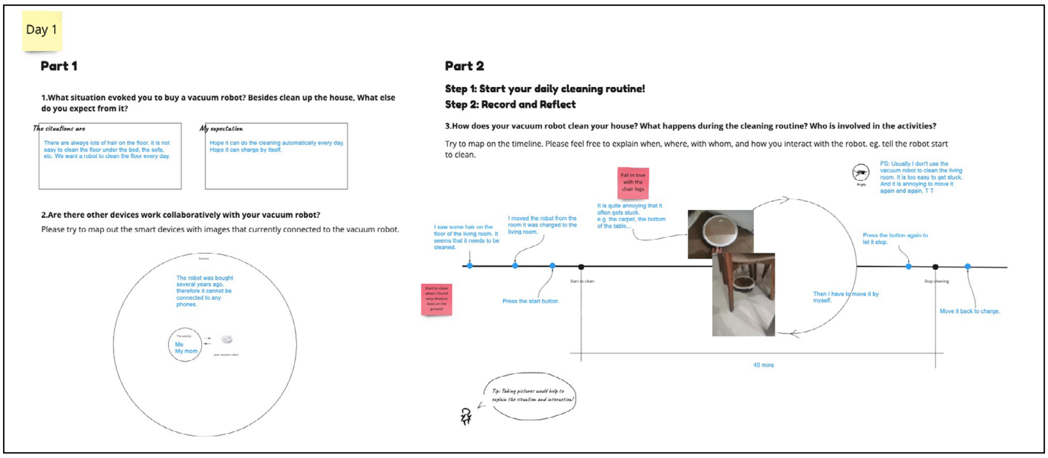


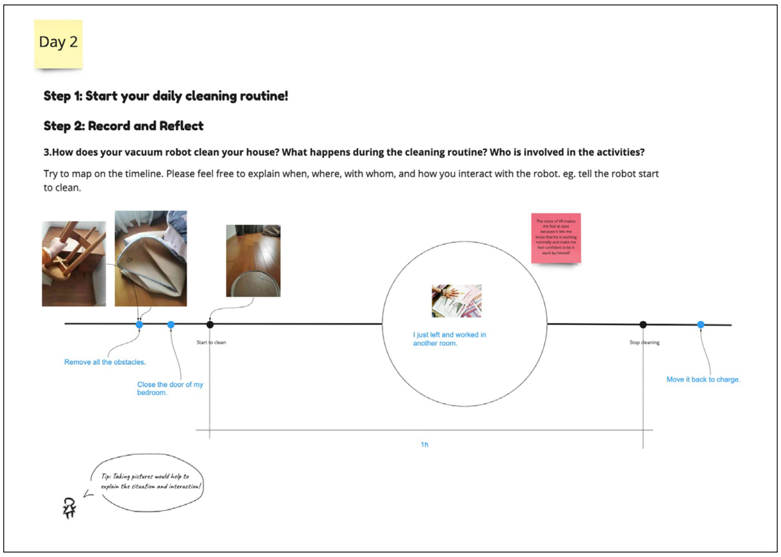


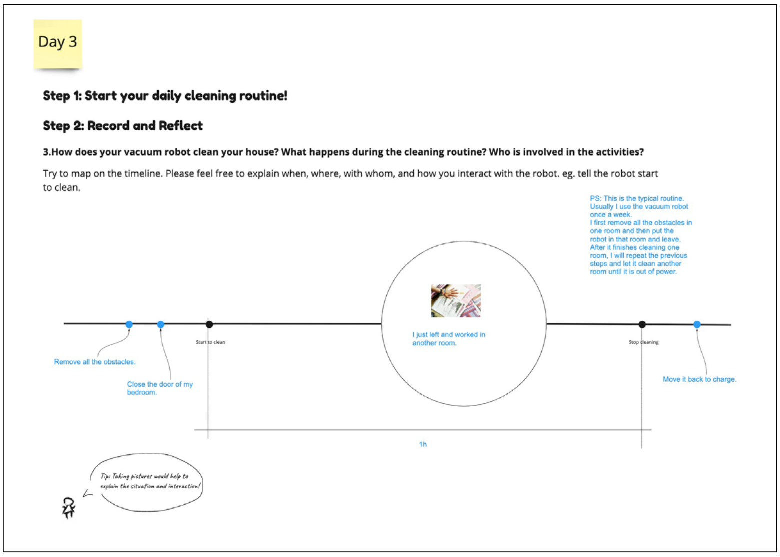


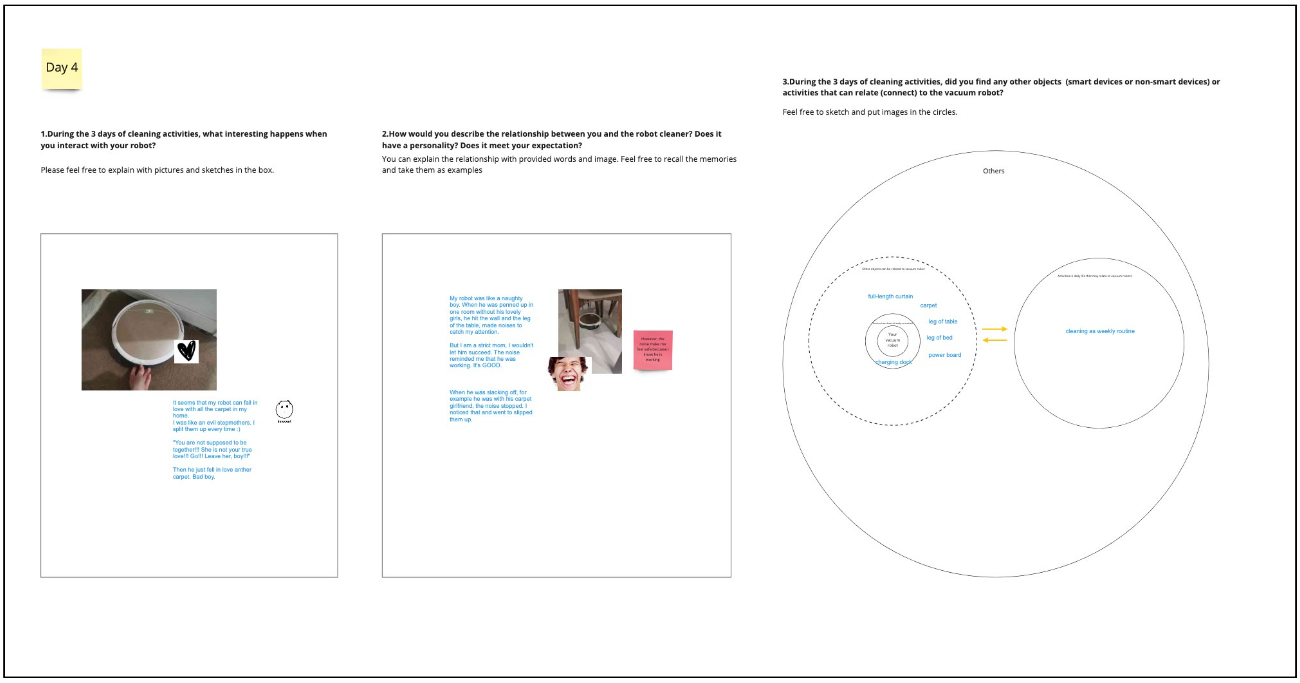


Appendix A - Diary booklet of participant c

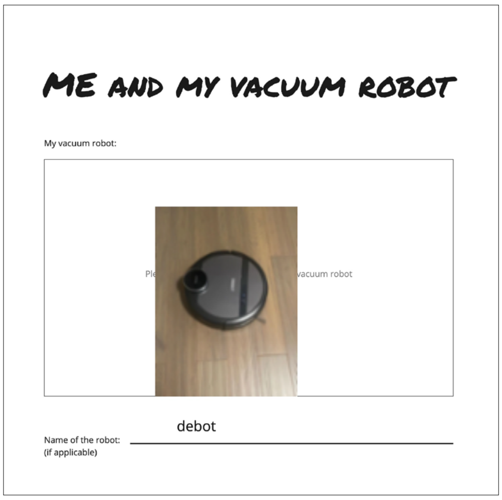


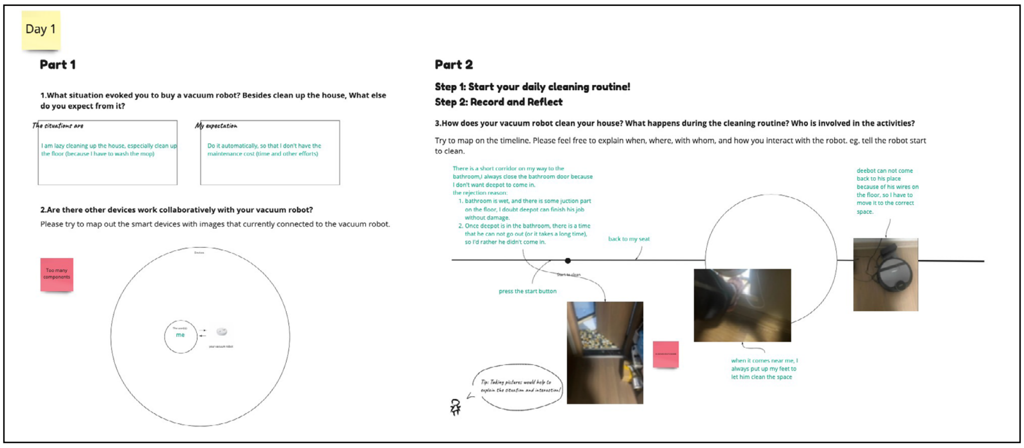


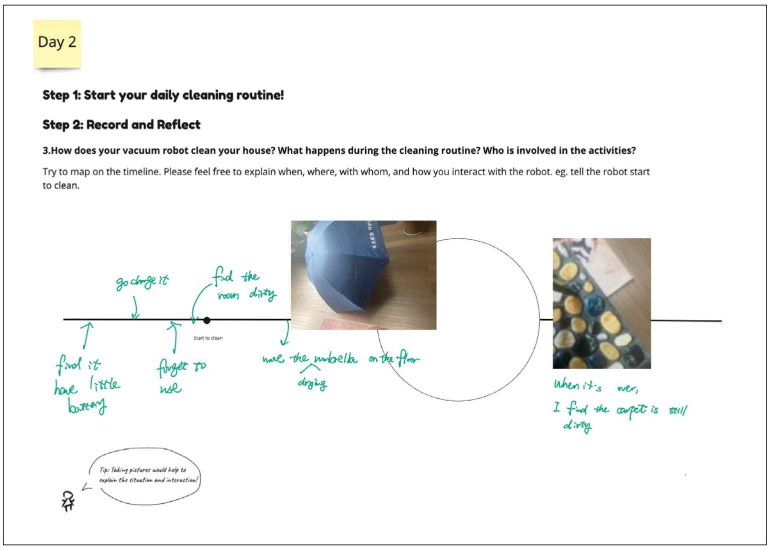


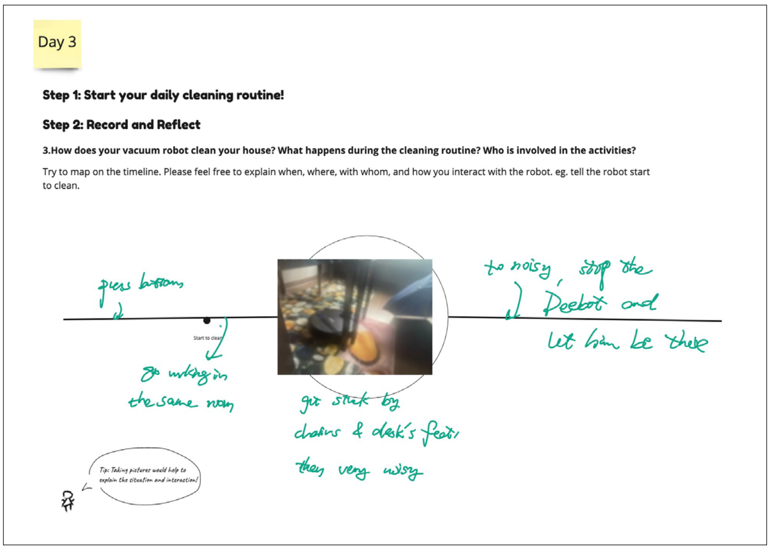


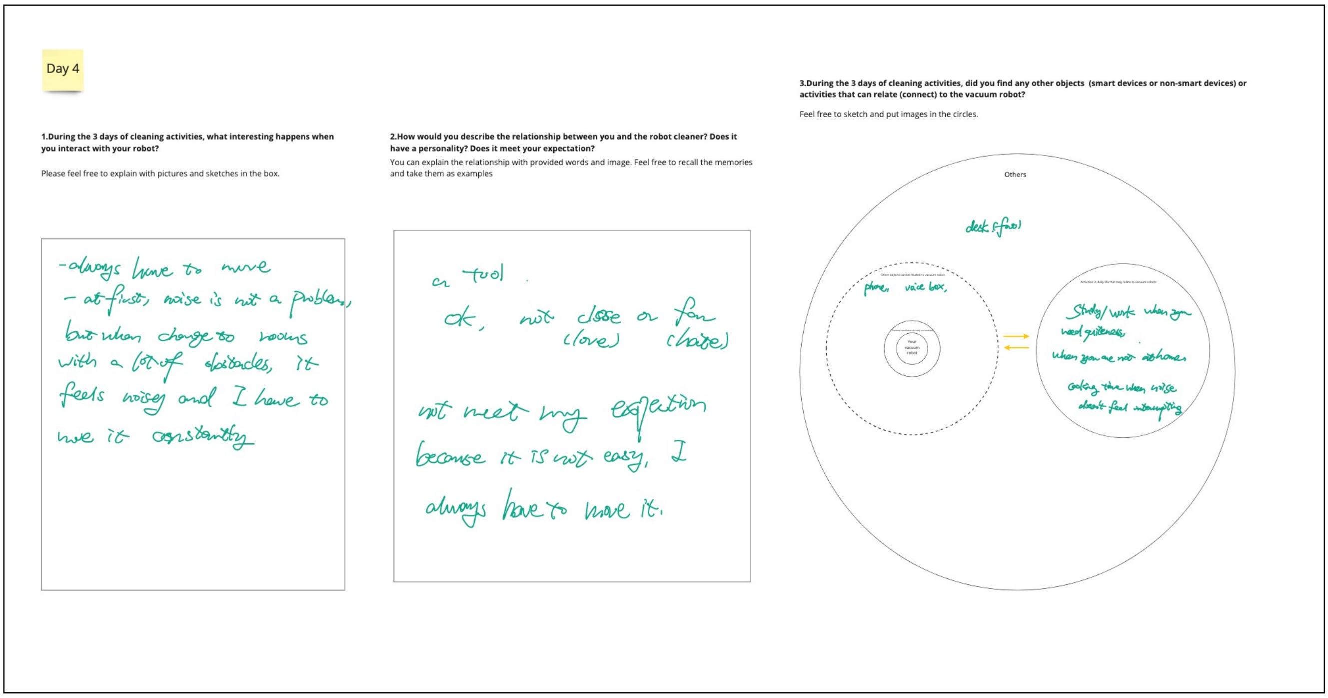
> Appendix A - Diary booklet of participant d



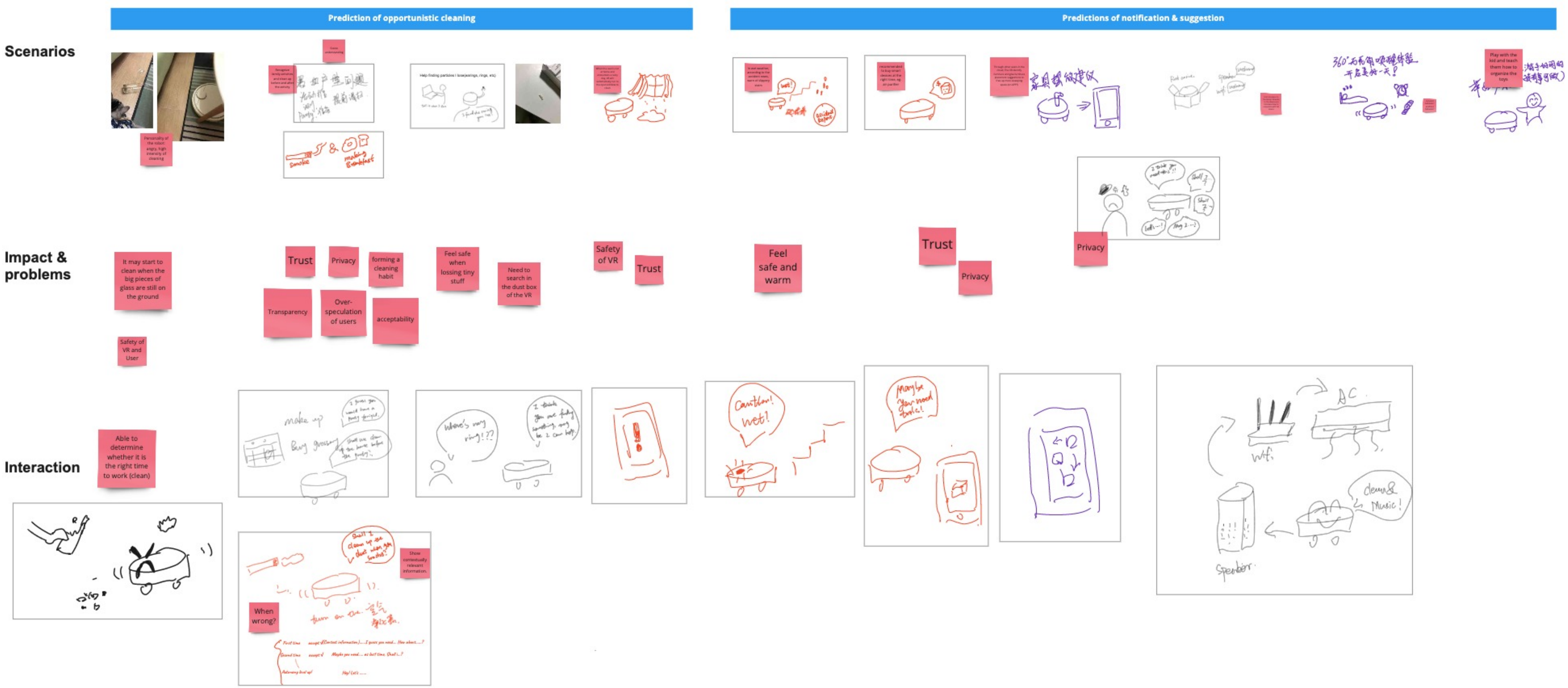








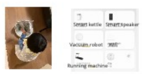
Appendix B - The raw data and sketches of creative session

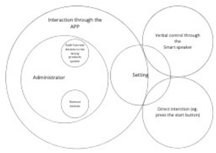


> Appendix C - categorizing the domestication qualities of current vacuum robot form the creative sessions (Part 1)

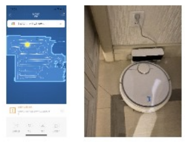
SMART OBJECT What qualities make smart object (Current vacuum robot) become part of our life?

PRACTICAL DOMESTICATION refers to the physical, observable interactions that users have with technology,





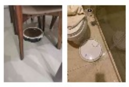
Provide diversified forms of interaction



Able to autonomously form a closed loop of action

Able to give feedback in proper ways and times

Able to sense users' enviroment



Master the work the user can't do or that would be more difficult for the user to do

Able to finish repetitive work and stick to the rules set by the users

SMART OBJECT What qualities make smart object (Current vacuum robot) become part of our life?

SYMBOLIC DOMESTICATION is the unobserved consequences of adopting the technology, i.e., what it means for the user to have the technology in their life.

"At this price, he can basically meet my expectations for the cleanliness of the home. He can clean on his own, and does not require me to spend a lot of effort to maintain the basic cleanliness of the home"

Assurance of the basic cleaningness

Preclean before the VR start to work

Helping the VR when cleaning

Enable to multitask

I just left and worked in another room.

A partner collaboratively finish the housework

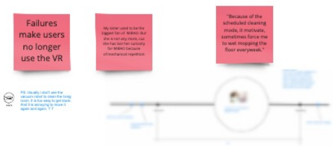
Robot as man, falling in love with carpet and chair legs

Able to foster new cleaning habit

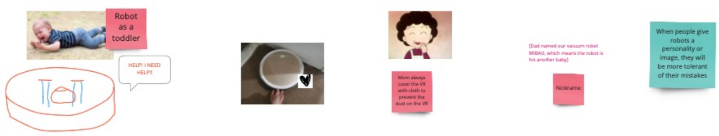
Appendix C - categorizing the domestication qualities of current vacuum robot form the creative sessions (Part 2)

SMART OBJECT What qualities make smart object (Current vacuum robot) become part of our life?

COGNITIVE DOMESTICATION refers to how the users learn from and through technology and the mental ontological practices relating to the use of the technology. How is technology enacted, and what change in practices does this entail?



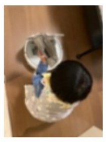
Able to trigger motivation in cleaning



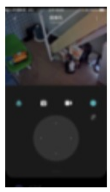
Able to trigger users to form personalities to perceive its perfomance

SMART OBJECT What qualities make smart object (Current vacuum robot) become part of our life?

SOCIAL DOMESTICATION e.g., how technology is co-produced not only by the individual but through a wide variety of actors who have agency in how the technology is being adopted into the life of users and others around them.



Actively and Passively involve more family members in housework and enable them to adapt to each other's cleaning habit



Trigger family engagement

Able to cooperate with the other smart devices within the family's ecosystem

Appendix D - categorizing the domestication qualities of predicting vacuum robot form the creative sessions (Part 1)

PREDICTING THING What qualities make the predicting vacuum robot become part of our life?

PRACTICAL DOMESTICATION refers to the physical, observable interactions that users have with technology,

PREDICTING THING What qualities make the predicting vacuum robot become part of our life?

SYMBOLIC DOMESTICATION on the other hand, is the unobserved consequences of adopting the technology, i.e., what it means for the user to have the technology in their life.

> Appendix D - categorizing the domestication qualities of predicting vacuum robot form the creative sessions (Part 2)

PREDICTING THING What qualities make the predicting vacuum robot become part of our life?

COGNITIVE DOMESTICATION refers to how the users learn from and through technology and the mental ontological practices relating to the use of the technology. How is technology enacted, and what change in practices does this entail?

PREDICTING THING What qualities make the predicting vacuum robot become part of our life?

SOCIAL DOMESTICATION e.g., how technology is co-produced not only by the individual but through a wide variety of actors who have agency in how the technology is being adopted into the life of users and others around them.

> Appendix E - Taxonomy of Levels of Robot Autonomy for HRI (Beer et al., 2014)

LORA	Sense	Plan	Act	Description	Examples from Literature
Manual	H	H	H	The human performs all aspects of the task including sensing the environment, generating plans/options/goals, and implementing processes.	"Manual Control" Endsley & Kaber, 1999
Tele-operation	H/R	H	H/R	The robot assists the human with action implementation. However, sensing and planning is allocated to the human. For example, a human may teleoperate a robot, but the human may choose to prompt the robot to assist with some aspects of a task (e.g., gripping objects).	"Action Support" Endsley & Kaber, 1999; Kaber et al., 2000; "Manual Teleoperation" Milgram, 1995; "Tele Mode" Baker & Yanco, 2004; Bruemmer et al., 2005; Desai & Yanco, 2005
Assisted Tele-operation	H/R	H	H/R	The human assists with all aspects of the task. However, the robot senses the environment and chooses to intervene with task. For example, if the user navigates the robot too close to an obstacle, the robot will automatically steer to avoid collision.	"Assisted Teleoperation" Takayama et al., 2011; "Safe Mode" Baker & Yanco, 2004; Bruemmer et al., 2005; Desai & Yanco, 2005
Batch Processing	H/R	H	R	Both the human and robot monitor and sense the environment. The human, however, determines the goals and plans of the task. The robot then implements the task.	"Batch Processing" Endsley & Kaber, 1999; Kaber et al., 2000
Decision Support	H/R	H/R	R	Both the human and robot sense the environment and generate a task plan. However, the human chooses the task plan and commands the robot to implement actions.	"Decision Support" Endlsey & Kaber, 1999; Kaber et al., 2000
Shared Control With Human Initiative	H/R	H/R	R	The robot autonomously senses the environment, develops plans and goals, and implements actions. However, the human monitors the robot's progress and may intervene and influence the robot with new goals and plans if the robot is having difficulty.	"Shared Mode" Baker & Yanco, 2004; Bruemmer et al., 2005; Desai & Yanco, 2005; "Mixed Initiative" Sellner et al., 2006; "Control Sharing" Tarn et al., 1995
Shared Control With Robot Initiative	H/R	H/R	R	The robot performs all aspects of the task (sense, plan, act). If the robot encounters difficulty, it can prompt the human for assistance in setting new goals and plans.	"System-Initiative" Sellner et al., 2006; "Fixed-Subtask Mixed-Initiative" Hearst, 1999
Executive Control	R	H/R	R	The human may give an abstract high-level goal (e.g., navigate in environment to a specified location). The robot autonomously senses environment, sets the plan, and implements action.	"Seamless Autonomy" Few et al., 2008; "Autonomous mode" Baker & Yanco, 2004; Bruemmer et al., 2005; Desai & Yanco, 2005
Supervisory Control	H/R	R	R	The robot performs all aspects of task, but the human continuously monitors the robot, environment, and task. The human has override capability and may set a new goal and plan. In this case, the autonomy would shift to executive control, shared control, or decision support.	"Supervisory Control" Endsley & Kaber, 1999; Kaber et al., 2000
Full Autonomy	R	R	R	The robot performs all aspects of a task autonomously without human intervention with sensing, planning, or implementing action.	"Full Automation" Endsley & Kaber, 1999

*Note: H = Human, R = Robot. Manual represents a situation where no robot is involved in performing the task; this level is included for a complete taxonomy continuum.

> Appendix F - Consent form for creative sessions

Consent form for participation in Creative session

Dear participant,

I am pleased to invite you to join my research and creative session for the project "Towards an active predictive relation by hacking study of vacuum robot", which is a graduation project of Peicheng Guo, Faculty of Industrial Design Engineering, Delft University of Technology.
The aim of the project is to develop a framework of design qualities for relations between human and a vacuum robot with predictive capabilities. To investigate the design qualities, an existing smart vacuum robot will be redesigned with predictive capabilities.

I'd like to ask you to read this form carefully and ask me any questions you might have.

1. Your participation in this research is completely voluntary. If you do not feel comfortable during the research and do not want to continue, you are free to withdraw at any time.
2. During the research, I will ask you to finish some exercises and answer questions referring to your personal experiences. If you don't feel comfortable to share, you have the right to skip any of these questions.
3. The research will have two parts:
    a. <u>Part 1: Context diary:</u>
    In this part, the diary templates will be provided to you through the miro board, to help you record your daily interaction with the vacuum robot. The diary consists of 4 days of exercise. To finish the exercise, it will take approximately 15 mins for each day. The diary will be served as inspiration and discussed with other participants in the next section.
    b. <u>Part 2: Creative session:</u>
    In this part, the project background will be first introduced to you and then you will be asked to review your diary and inspired each other to evoke the thoughts on the predictive knowledge. The creative session will take approximately 1h and 30mins.
    <u>Procedure</u>
        i. Introduction of the project background (5mins)
        ii. diary review (20mins, 5mins for each participant)
        iii. Session1(15mins):
            1. Brainstorming & Sketching (5mins)
            2. Discussion (10mins)
        iv. Session2 (15mins):
            1. Brainstorming & Sketching (5mins)
            2. Discussion (10mins)
        v. Session3(15mins):
            1. Brainstorming & Sketching (5mins)
            2. Discussion (10mins)
        vi. End up

In part 2, I will take notes and screen recording (online interview). If you do not want to be recorded, you are free not to take part in the research. Please check any boxes you give permission to:

- ☐ Being filmed and the voice being recorded.
- ☐ Photos being used in academic publications. The personal identity will be protected by blurring the face.

All information will be used for an internal purpose and in any sort of publication I will not include any information that will make it possible to identify you.

I have read the description of the study and of my rights as a percipient and I have received the answer to everything I asked. I hereby voluntarily agree to patriciate in this study.

Signatures

______________________	______________________	______________________
Name of participant	Signature	Date

have accurately read out the information sheet to the potential participant and, to the best of my ability, ensured that the participant understands to what they are freely consenting.

Peicheng guo	[signature]	2021.03.11
Researcher name	Signature	Date

Appendix G - Questionnaire for the evaluation (1)

Qualitative interview & Questionnaire

<u>Questions for Proposition 1</u>

At the end of each round:

1. Why did you say yes(no/other commands in the test) to the vacuum robot?
2. Why did you rate……?

At the end of the test:

1. Did you realize the differences between each round? What are they?
2. What do you think of the differences?
3. Did the differences influence your feeling about the robot?

<u>Questions for Proposition 2 and the general experience (<15mins)</u>

At the end of the test:

1. Could you describe the experience you had with the vacuum robot?
2. Can you tell the different feel of the two scenarios?
3. To what extent do you accept this technology? why? (scale)

<u>Question for Practical dimension:</u>

What elements of the predicting vacuum robot do you like or find helpful in the test?

<u>Recognizability of the practical quality</u> Statement 1: I think the robot **is able to provide rooms for negotiation on the decision made by the robot.** Strongly disagree 0 1 2 3 4 5 Strongly agree
<u>Validity of the practical quality</u> I think the quality described in statement 1 helps me to accept the predictive behavior of the vacuum robot. Strongly disagree 0 1 2 3 4 5 Strongly agree

Statement 2: I think the robot **is able to easily dismiss undesired services, such as performing actions in improper time.** Strongly disagree 0 1 2 3 4 5 Strongly agree

> Appendix G - Questionnaire for the evaluation (2)

I think the qualities described in statement 2 help me to accept the predictive behavior of the vacuum robot Strongly disagree 0 1 2 3 4 5 Strongly agree

Statement 3: I think the robot **is able to show contextually relevant information <u>and provide an explanation of the reason when needed.</u>** Strongly disagree 0 1 2 3 4 5 Strongly agree
I think the qualities described in statement 3 help me to accept the predictive behavior of the vacuum robot Strongly disagree 0 1 2 3 4 5 Strongly agree

<u>Question for Symbolic dimension:</u>

What does it mean for you to have this predicting vacuum robot in your life?

<u>*Recognizability of the symbolic quality*</u> Statement 5: I think the predicting robot **means the assurance of housekeeping.** Strongly disagree 0 1 2 3 4 5 Strongly agree
<u>*Validity of the symbolic quality*</u> I think the quality described in statement 5 helps me to accept the predictive behavior of the vacuum robot. Strongly disagree 0 1 2 3 4 5 Strongly agree

Statement 7: I think the predicting robot **is able to foster a new lifestyle.** Strongly disagree 0 1 2 3 4 5 Strongly agree
I think the quality described in statement 7 helps me to accept the predictive behavior of

> Appendix G - Questionnaire for the evaluation (3)

the vacuum robot. Strongly disagree 0 1 2 3 4 5 Strongly agree

<u>Question for Cognitive & Social dimension:</u>

What do you learn from the predicting vacuum robot? and how?

<u>*Recognizability of the cognitive & social quality*</u> Statement 8: I think the predicting robot **can motivate me to constantly participate in generating predictive knowledge for other users** Strongly disagree 0 1 2 3 4 5 Strongly agree
<u>*Validity of the cognitive & social quality*</u> I think the quality described in statement 8 helps me to accept the predictive behavior of the vacuum robot. Strongly disagree 0 1 2 3 4 5 Strongly agree

Statement 9: I think the predicting robot **can motivate me to provide feedback in order to make the new (predictive) behaviors more suitable in my context.** Strongly disagree 0 1 2 3 4 5 Strongly agree
I think the quality describe in statement 9 help me accept the predictive behavior of the vacuum robot. Strongly disagree 0 1 2 3 4 5 Strongly agree

Statement 11: I think **I will be more sensitive about my well-being when I have a predicting robot.** Strongly disagree 0 1 2 3 4 5 Strongly agree
I think the quality describe in statement 11 help me accept the predictive behavior of the vacuum robot Strongly disagree 0 1 2 3 4 5 Strongly agree

DESIGN FOR our future

TU Delft

IDE Master Graduation

Project team, Procedural checks and personal Project brief

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

- The student defines the team, what he/she is going to do/deliver and how that will come about.
- SSC E&SA (Shared Service Center, Education & Student Affairs) reports on the student's registration and study progress.
- IDE's Board of Examiners confirms if the student is allowed to start the Graduation Project.

USE ADOBE ACROBAT READER TO OPEN, EDIT AND SAVE THIS DOCUMENT
Download again and reopen in case you tried other software, such as Preview (Mac) or a webbrowser.

STUDENT DATA & MASTER PROGRAMME

Save this form according the format "IDE Master Graduation Project Brief_familyname_firstname_studentnumber_dd-mm-yyyy". Complete all blue parts of the form and include the approved Project Brief in your Graduation Report as Appendix 1 !

family name: Guo 4784
initials: P given name: Peicheng
student number:
street & no.:
zipcode & city:
country:
phone:
email:

Your master programme (only select the options that apply to you):
IDE master(s): IPD / DfI (selected) / SPD
2nd non-IDE master:
individual programme: - - (give date of approval)
honours programme: Honours Programme Master
specialisation / annotation: Medisign / Tech. in Sustainable Design / Entrepeneurship

SUPERVISORY TEAM **

Fill in the required data for the supervisory team members. Please check the instructions on the right !

** chair: Nazli Cila dept. / section: HCID
** mentor: Iskander Smit dept. / section: HCID
2nd mentor:
organisation:
city: country:

comments (optional): The project is based on Smit research topic and it's also related to Cila's research background. So they will be the best mentors to guide me through the theory and design method regarding human robot interaction (HRI)

Chair should request the IDE Board of Examiners for approval of a non-IDE mentor, including a motivation letter and c.v..

Second mentor only applies in case the assignment is hosted by an external organisation.

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

APPROVAL PROJECT BRIEF

To be filled in by the chair of the supervisory team.

chair Nazlı Cila date 02 - 03 - 2021 signature Nazli Cila - IO Digitally signed by Nazli Cila - IO Date: 2021.03.02 17:43:05 +01'00'

CHECK STUDY PROGRESS

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

Master electives no. of EC accumulated in total: 21 EC

Of which, taking the conditional requirements into account, can be part of the exam programme 21 EC

List of electives obtained before the third semester without approval of the BoE

YES all 1st year master courses passed

NO missing 1st year master courses are:

name J. J. de Bruin date 04 - 03 - 2021 signature J. J. de Bruin, SPA Digitally signed by J. J. de Bruin, SPA Date: 2021.03.04 12:09:47 +01'00'

FORMAL APPROVAL GRADUATION PROJECT

To be filled in by the Board of Examiners of IDE TU Delft. Please check the supervisory team and study the parts of the brief marked **. Next, please assess, (dis)approve and sign this Project Brief, by using the criteria below.

- Does the project fit within the (MSc)-programme of the student (taking into account, if described, the activities done next to the obligatory MSc specific courses)?
- Is the level of the project challenging enough for a MSc IDE graduating student?
- Is the project expected to be doable within 100 working days/20 weeks ?
- Does the composition of the supervisory team comply with the regulations and fit the assignment ?

Content: ★ APPROVED / NOT APPROVED

Procedure: APPROVED / NOT APPROVED

- remark: title not clear

comments

name Monique von Morgen date 16 - 03 - 2021 signature

Initials & Name P Guo 4784 Student number 5028191

Title of Project Towards an active predictive relation by hacking study of vacuum robot

Towards an active predictive relation by hacking study of vacuum robot — project title

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

start date 22 - 02 - 2021 | 15 - 07 - 2021 end date

INTRODUCTION **

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

Things are becoming connected, such as electronic consumer products, being able to connect to each other through the Internet and can interact without human interference (Rowland et al., 2015). By implementing sensors, things can exchange data and shift a single product to a decentralized system. This system of connected objects is called the Internet of Things (IoT).

Vacuum robots can be considered as a poster child for the connected objects. By collecting and exchanging data with sensors, the vacuum robot is very good at avoiding objects, creating patterns, and returning to its charging point on time. XiaoMi’s vacuum robot implements a 3D sensor recognizing the difference between objects such as a toy and the leg of a chair, detecting even small objects on the floor. An object recognition algorithm allows it to identify objects of all kinds and map the safest, most efficient route. Samsung’s JetBot 90 AI+ Vacuum robot allows users to connect their smartphone, schedule a cleaning session, set “no-go zones” on a map of their homes, or even connect to its camera to keep an eye on users’ home and pets while they are away.

However, the vacuum robots mentioned above are all integrated with the adaptive system which updates and profiles for scripted behavior (Smit, 2020). As Smit described, with the development of Artificial intelligence and Machine learning capabilities, the predictive capabilities are added to the connected objects and changing the character of the things to "things that predict". If a vacuum robot with a predictive system not only profiles for scripted behavior but could also use knowledge from all the other vacuum robots in the world that encounter similar situations, it can make predictions based on that. In this case, a new type of interplay between humans and things called "predictive relation" is created. Here, the decentralized systems reveal knowledge about the possible future, and this interplay shapes the functional working of the devices, which is not a fixed state. However, the reasons for the decision made by the predictive knowledge are sometimes hidden within their algorithm. For instance, you may not realize the reason why Netflix thinks that a particular movie suits you. This creates the design space for the predictive relation, i.e., a way for users to establish a relation with the future and produce a mental model of how the system is operating.

This project will use the concepts of prediction in a ‘ hacking case study’ of a XiaoMi’s vacuum robot to extend it with predictive capabilities. The research will investigate the impact of a new predicting vacuum robot by creating a ‘wizard-of-oz’ prototype and studying its interactions with the users and/or designer.

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introduction (continued): space for images

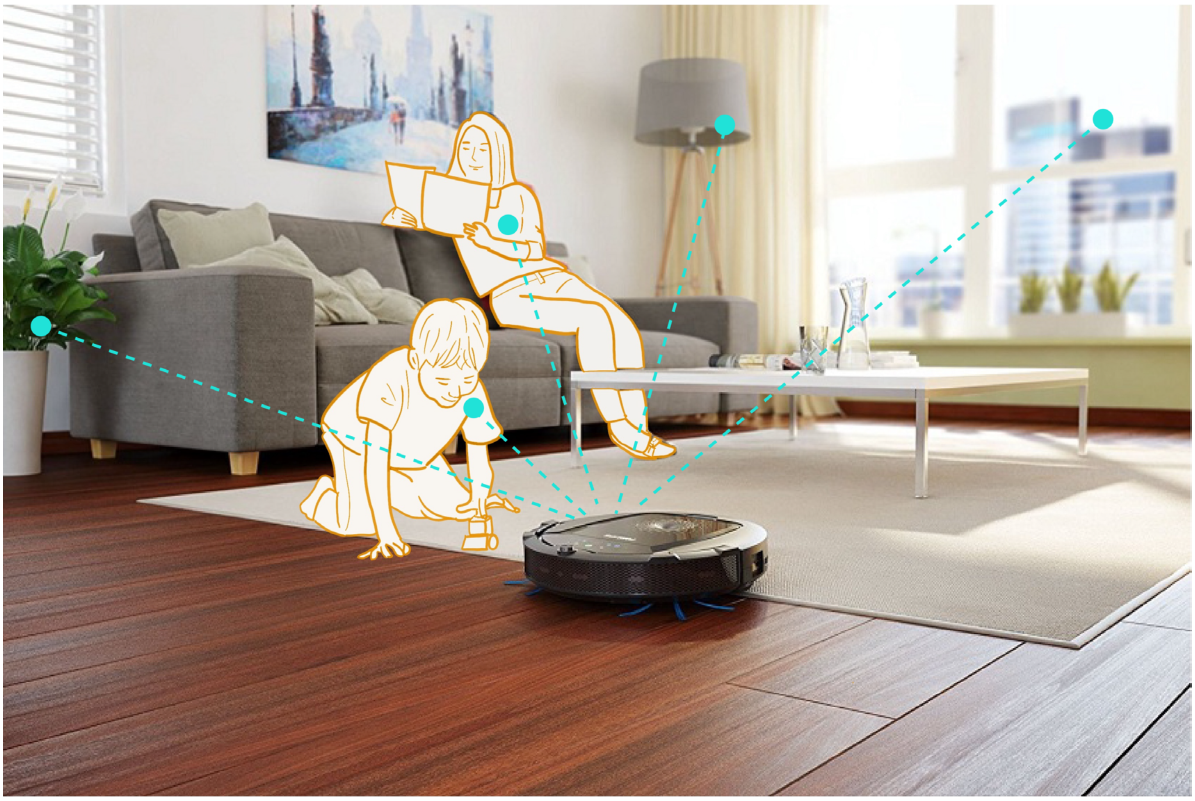


image / figure 1: Scenario of vacuum robot interacting with users

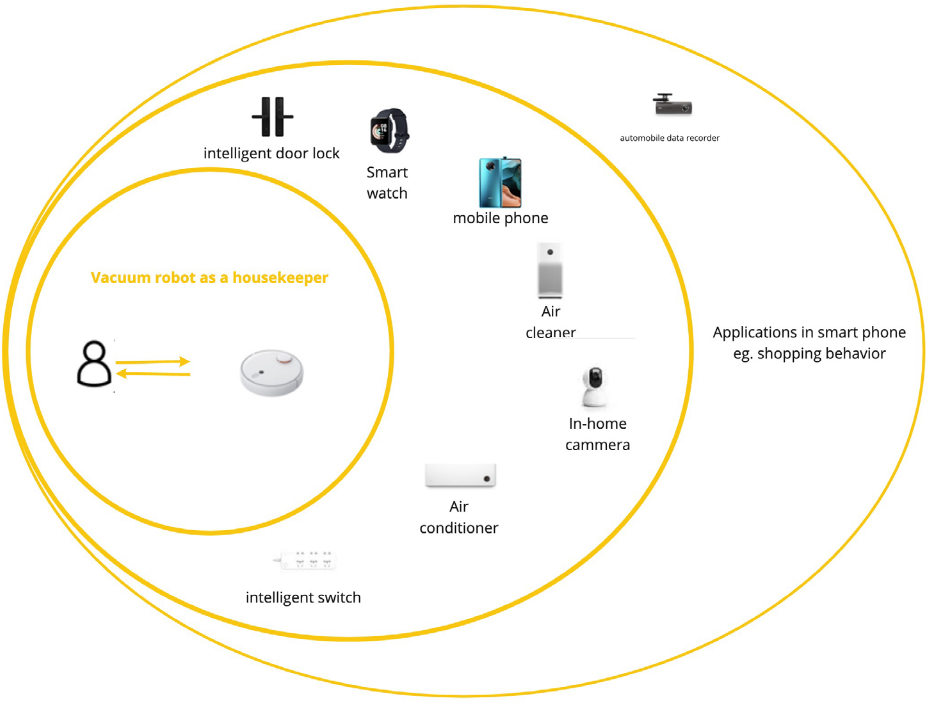


image / figure 2: Ecology system of XiaoMi's products

Initials & Name P Guo 4784 Student number 5028191

Title of Project Towards an active predictive relation by hacking study of vacuum robot

PROBLEM DEFINITION **

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

Machine learning capabilities and AI power can make things become predictive and create knowledge on possible futures beyond the users' expectations. The predictive knowledge may take over the decision making and the reasons for the predictive decision are sometimes missing, leaving the user with passive use. As a user, you cannot reason it out yourself, knowledge is used that surprises you, but ultimately suit you. Many well-known examples such as the suggestions of Google search have already come up with the solution, but cases are few when looking into the IoT products. (Smit, 2020) Now the predictive relation we have with the connected objects, cannot be the 'background relation' that meets the requirement when the interplay is linking to the future. It is urged to have an active and valid dialogue to understand the now and the future, and this leads to the question: 'how to design predictive relations for the things that predict?' Therefore, to investigate the question, the project will explore the predictive relations and identify the design qualities for predictive relations between human and thing by taking the XiaoMi' Vacuum robot as the starting point of the case study.

The following sub research questions are set up for this case study:

1. How does the vacuum robot work in the current situation?
2. What are the differences of seeing the world and context between the user perspective and the vacuum robot perspective?
3. What are the possibilities of the predictive capabilities of vacuum robot?
4. With the extended predictive capabilities, how should vacuum robot interact with human and improve trust and transparency?

Scope:

The studies will be conducted on the Xiaomi home devices and its ecology system. (Figure 2)

ASSIGNMENT **

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

The deliverable of this project is a framework of design qualities for relations between human and a vacuum robot with predictive capabilities. To investigate the design qualities, an existing smart vacuum robot will be redesigned with predictive capabilities.

The hacking case study will be conducted into 3 phases:

1. Understand the intelligent behavior of vacuum robot: Literature review, observation, and interview on the working of vacuum robot
2. Understand the context and find out the possibilities of predictive capabilities:
   a) Research on the user perspective: context mapping & service blueprint
   b)Research on the thing perspective: interview with thing
3. Extend and adjust the predictive capabilities:

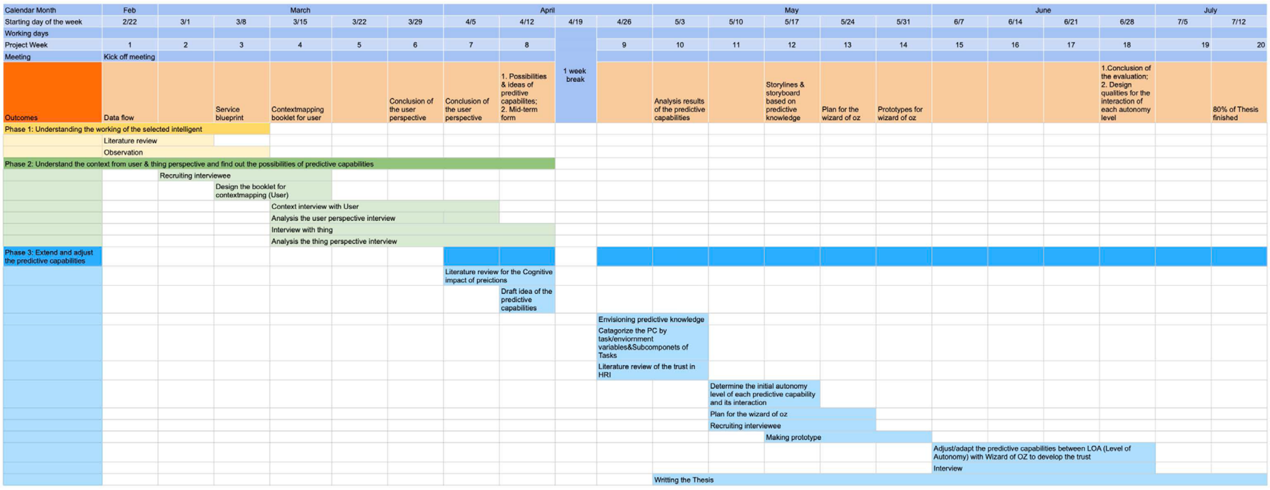
In this phase, the research will conduct through the framework of Levels of Robot Autonomy (Beer et al., 2014, p. 74) to explore the interaction of decision making & robot autonomy with extended predictive capabilities by wizard of oz:
   a) Envisioning predictive knowledge & Analysis of the predictive capabilities
   b) Determine the initial autonomy level of each predictive capability and its interaction when it first takes place in the context
   c) Evaluate & Adapt the predictive capabilities between LOA (Level of Autonomy) with Wizard of OZ to develop trust & transparency
   d) Validate the interaction of each autonomy level and translate them into the design qualities

PLANNING AND APPROACH **

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

start date 22 - 2 - 2021

15 - 7 - 2021 end date



96 Initials & Name P Guo 4784 Student number 5028191

Title of Project Towards an active predictive relation by hacking study of vacuum robot

MOTIVATION AND PERSONAL AMBITIONS

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

1) Understand and research the AI of the internet of things systematically.
According to my first internship in Microsoft, I gained interest in creating a predictable and harmonious system that is optimized for working with users to earn their trust. From the internship, I am fully aware of the immense potential and design space that artificial intelligence owns in user experience design. As a witness of how the internet has changed the world in the past ten years, I am also passionate about the UX of IoT and thrilled to spare my expertise obtained from my study of design.

2) Learn and deepen my knowledge on the research method of Interview with Things
During the study of DfI, I learned about Giaccardi research method —— Interview with thing (Giaccardi, 2016), and was deeply inspired by her speech. When searching for the graduation project, I was deeply attracted that this project not only covers the fields I am interested in —— IoT and AI, but also can the Things perspective to conduct research. So in this project, I want to learn the research method of Interview with things and apply it to my design practice.

FINAL COMMENTS

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