IMPROVING USER EXPERIENCE BY A SMART BATHROOM FLOOR CLEANER IN DIFFERENT CULTURE CONTEXTS

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November, 2019

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Master Thesis
November, 2019

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ACKNOWLEDGEMENT

Thanks to my great supervisors Imre Horváth and Jan Carel Diehl for supporting and guiding me through this project. I remember the first day you told me the first day that how fertile and amazing the Cyber-physical systems are, and guided me to explore this brand new world. The world is becoming more and more attractive to me during this exploring journey. Thanks for sharing your knowledge with me and always encouraging me to think more and do better.

Thanks to the fellow students who participated in the interviews and evaluation sessions. Some of you are far away in China, you still actively provided me with telephone or video interviews and other help. The project cannot be done without your help. Some of the Dutch participants, although we don't know each other, still gave me a lot of help, which makes me feel very warm.

Thanks to my dear friends, without your supporting and accompany, I might not be able to stick to the project and passed some dark times. I will always remember the happy time with you during these two years in Delft.

Last but not least, my deepest gratitude to my parents. It is your unconditional love and support that allows me to go further and to see a bigger world.

SUMMARY

Bathroom cleaning is one of the troublesome daily issues. Hair, dirty water, soap scum... all kinds of contaminants on the bathroom floor take people a lot of time and effort to deal with. With the development of computational technologies, smart products are gradually entering into our lives to solve these troublesome issues. Therefore, there is a chance to use new technologies to solve the bathroom floor cleaning problem and to make life convenient. Obviously, different people have different attitudes towards smart products, which influence their preferences on interacting with smart products. Based on my personal experience, Chinese and Dutch young adults have this difference, and are chosen as the target groups. To sum up, this project aims to explore the interaction with a smart bathroom floor cleaner in Chinese and Dutch cultural contexts.

The main challenge is to collect and analyze information from different aspects, and then integrated into a complex system, namely a smart bathroom floor cleaner system. The related aspects include context, user experience, smart product technologies, etc. We analyzed the bathroom environment conditions, the cleaning related concerns, the expected cleaning experience, promising technologies, Cyber-physical systems principles, and the opportunities in Chinese and Dutch smart product markets. The results show that the two groups have no significant differences in bathroom usage and cleaning habits. The expected experience for both groups is trustworthy and effortless. However, their attitudes towards smart products are different. The Chinese group has higher interest, while the Dutch group is more conservative. This difference is also consistent with the difference in the smart product markets. Therefore, we designed different interaction concepts based on the device in different intelligence levels in the conceptualization phase.

In order to design an interaction concept, at first we need a device concept that can meet the requirements of the bathroom cleaning. This device concept is formed by two cleaning robots and a base station. It has physical functions and cognitive functions about the bathroom cleaning. Then, the generation of the interaction concepts is based on the device concept's variants with different intelligence levels. Supplemented by interaction techniques and emotional expectations, different interaction concepts were defined.

To analyze the experience of these interaction concepts, we refined the concepts. Through the storyboard and prototypes, participants evaluated these concepts. The results showed that the interaction concept with the most intelligent device could best reach the expected experience. At the same time, interaction elements in other concepts (e.g. using mobile apps to show complex information) also received positive feedback. In the end, we chose the interaction concept with the most intelligent device concept, with elements from other concepts as supplements, and had the final interaction concept. The final evaluation indicated that the concept is able to make the cleaning experience effortless. Users have trust in the cleaning ability of the device. However, trust in machine intelligence is not enough yet. In the end, we provided recommendations for the difficulties encountered throughout the project and the areas that can be improved in the results.

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1. ORIENTATION

1.1 Problem definition

With the development of computational technologies, smart products are gradually entering into the life of humans to help solve their daily problems. Since bathroom cleaning is one of the troublesome daily issues, the need for a smart bathroom cleaner has emerged (Figure 1). However, there are not only technological problems to be solved in the case of such emerging smart products but also non-technological ones (e.g., how they will interact with users?). Obviously, smart products are supposed to perform differently with different user groups or in different use contexts. This means that the interaction may vary according to cultural backgrounds. In this project, 'culture' includes habits of bathroom usage and cleaning, and the attitude towards smart products. My personal experience suggests considering the fact that Chinese and Dutch people have different bathrooms or smart product usage habits. To sum up, the interaction between a smart bathroom floor cleaner and users in Chinese and Dutch cultural contexts forms the phenomenon that will be studied in this project.

1.2 Opportunity

The aspiration for having cyber-physical systems (CPSs) emerged decades ago. However, the enabling technologies are becoming available just in recent years. Thus, there is a huge space to be explored with regards to CPSs. In this project, the operation and implementation principles of smart CPSs (S-CPSs) will be operationalized on the smart bathroom floor cleaner as technological implementation. The interaction and user experience studies are also based on the knowledge of S-CPSs. Besides, my interests are in user experience and culture in design. After previous research, there is not much smart device in the current market that seriously considered the user experience in the cultural aspect. In this project, these opportunities will be investigated by a smart bathroom floor cleaner to improve user experience in different cultural contexts (Figure 2).

1.3 Scope

The overall objective of this project is to offer a solution for Chinese and Dutch people in the context of bathroom floor cleaning. The product (smart bathroom floor cleaner), the environment (bathroom floor), and the cultural context (Chinese and Dutch) are carefully scoped, and the major task (to clean the bathroom floor) is clearly defined.

The concept of the envisioned product has two components. One is the physical device, and the other is the interaction between the device and human. Considering the graduation orientation, we will work on the interaction issues, rather than on comprehensive development of the product. As for technological implementation, the principles of S-CPSs will be operationalized.

1.4 Approach

The challenge of this project lies in the limitations concerning the knowledge about S-CPSs and integrating the knowledge from various disciplines. To complete the project, the following four phases consist of the approach: researching, conceptualizing, prototyping and evaluation.

During the researching phase, different domains of interests associated with this project will be studied. The research outcomes will be summarized into three related aspects of requirements: context related, technology related, and business related. The requirements quantified the knowledge into the conceptualizing phase. Several ideas of the physical devices and their related interaction ways will be put forwarded. After evaluating the early ideas, one integrated conception of the device and the interaction way will be chosen. During the prototyping phase, the intended interaction will be developed into detailed experimental prototypes that could let the users experience the interaction and do the user tests. The performance of the physical device will be demonstrated during the user test to enhance the experience. At last, a final concept will be evaluated to find if it actually improves the user experience, with a list of recommendations on the further development of future smart products, as well as the cultural effects concerning a multi-aspect interaction with a specific smart cyber-physical system. (Figure 3)

1.5 Deliverables

The final deliverables include:

- A detailed report that contains the final concept with the development process.
- A conception movie that clarifies the expected implementation of the project.
- Recommendations for further development.

Figure 1. Bathroom floor cleaning method: Present vs Future

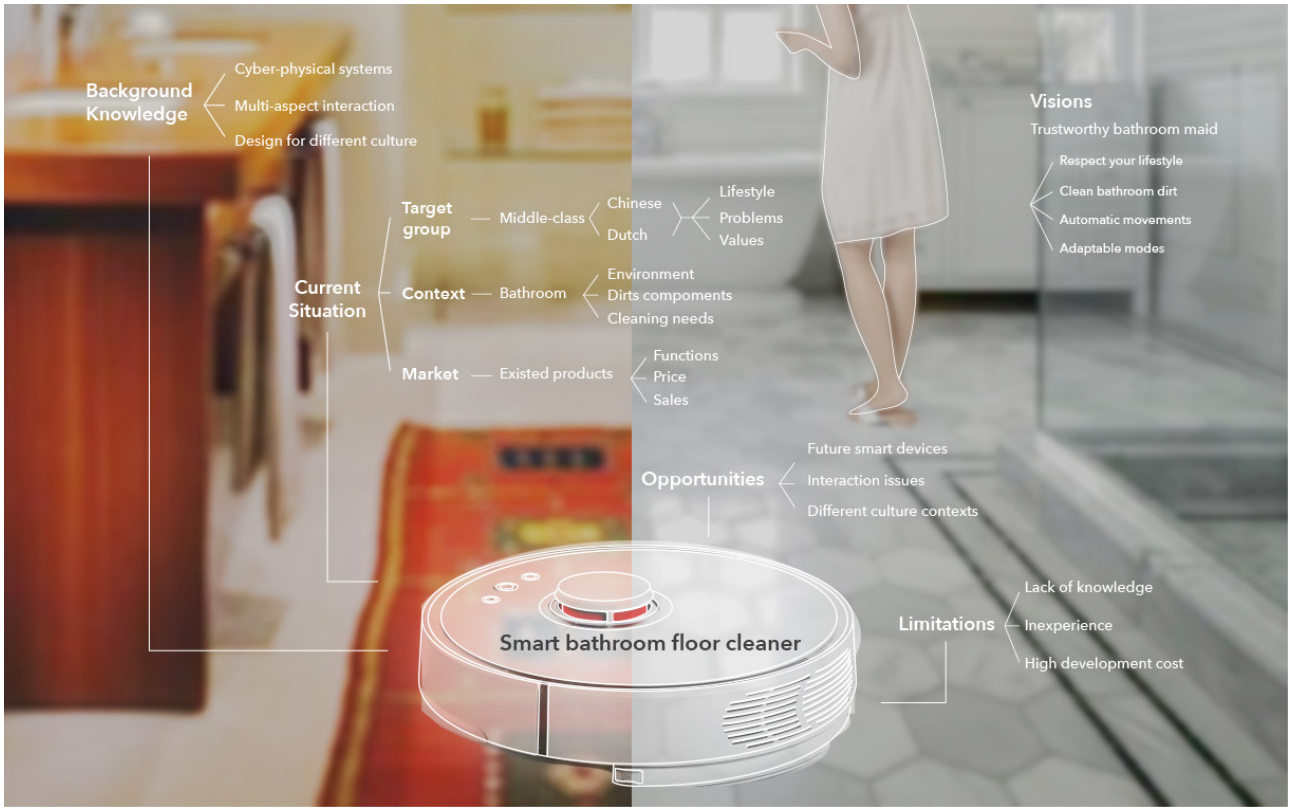


Figure 2. Vision of smart bathroom floor cleaner

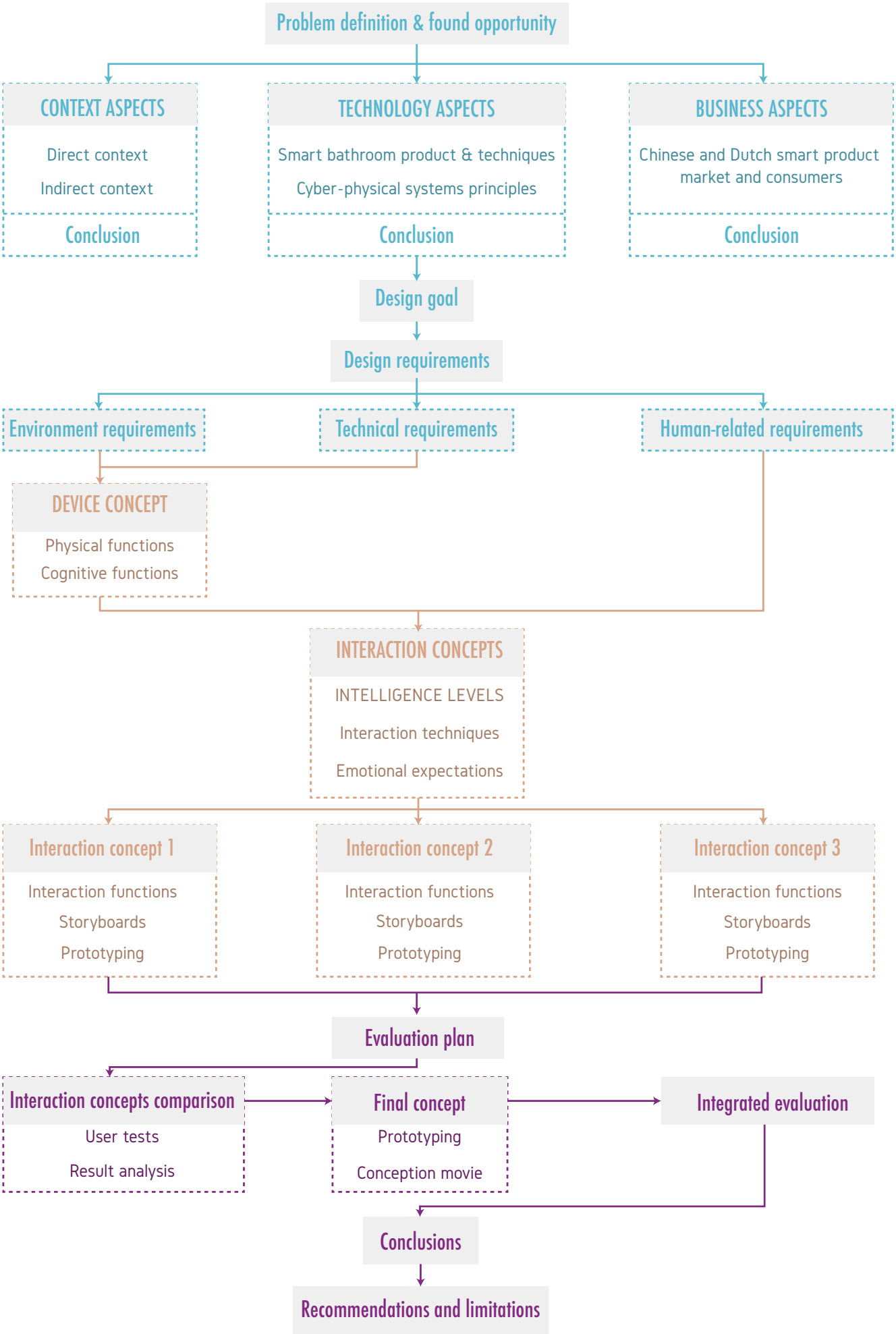


Figure 3. Overview of the objective

2 ANALYSIS

The overall objective of this project is to design a smart cleaner to improve the bathroom room floor cleaning experience for young adults who share a bathroom. Besides, the cultural contexts of the target users were set in China and the Netherlands.

In order to reach this aim, researches were done in several related domains: user, interaction, bathroom environment, smart product, market, and culture influences. For each domain, the researches were done from present to future dilemmas, to be more specific, the current usage & cleaning, and the future usage & cleaning. Then, the results of every domain were collated into three aspects: the context, the technology, and the business (Figure 4).

As is shown in figure 5, each column shows the research methods for a particular domain. For instance, when studying the bathroom environment, research methods include literature research, website research, and observation. Then, the research outcomes will be summarized into three related aspects of requirements, and quantify into a design space.

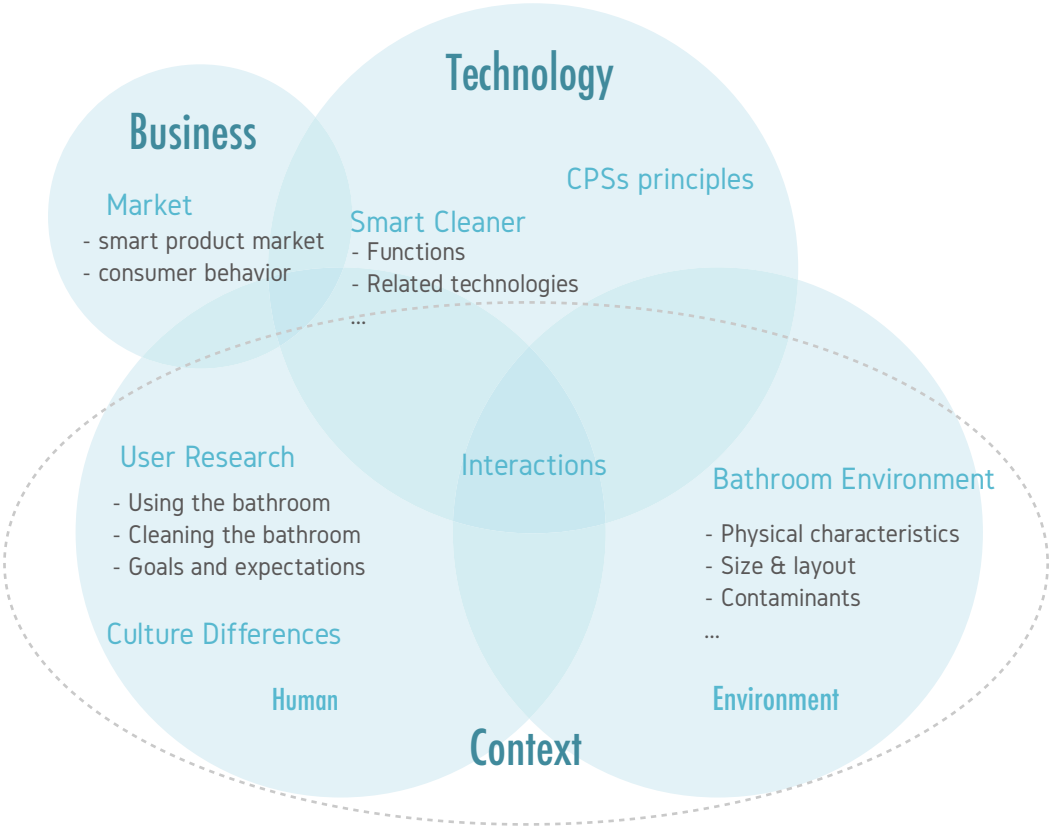


Figure 4. Analysis aspects

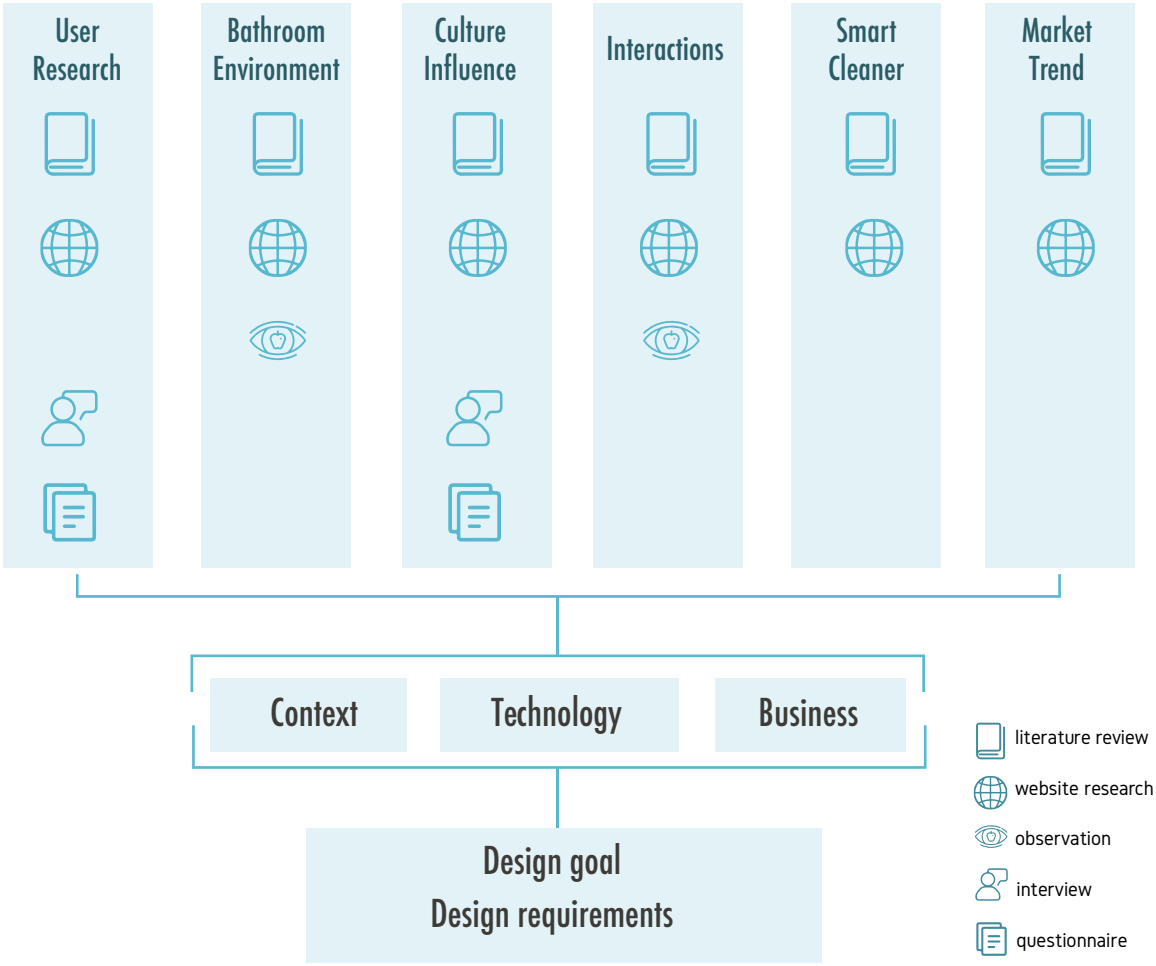


Figure 5. Researches methods for each domain

2.1 CONTEXT ASPECTS

2.1.1 Introduction

Context has been interpreted variously by different researchers, depending on the aspect of consideration [1]. A context specification may include the direct environmental context, for example, information about space, physical characteristics of the space, nearby objects, etc. It was also observed that some concepts describe the context from the premise of human-computer interaction or interfacing [1]. To sum up, the system context can be differentiated as a direct context and an indirect context. The direct context includes the explicit factors, also can be described as the direct environment. The indirect context means the implicit factors, such as the objective of human.

In this project, the domestic bathroom that the envisioned smart cleaner will operate in is the direct context. People's objectives and their expectations for their bathroom, as well as for this smart cleaner, form the indirect context.

2.1.2 Approaches

2.1.2.1 Research goals

Direct context:
The goal of this study is to understand what is the physical environment that the smart cleaner will directly operate in and to find the cleaning-related challenges that it may face. The subgoals are:

RG1 Knowing the ambient characteristics of the domestic bathroom that may influence the operation of the smart cleaner.
RG2 Knowing the cleaning-related characteristics of the domestic bathroom. For instance, the typical layout, fitments, and the main contaminants on the floor.
RG3 Finding the target user's expectations of the physical bathroom environment.

Indirect context:
After defining the target user, the aim of this part is to understand how the target users currently use and clean their bathroom and what is their expected experience, in order to find the cleaning issues that should be addressed by the envisioned product and the interaction experience that should be achieved. The subgoals are:

RG4 Understanding the current usage and cleaning habits of the target Chinese and Dutch users.
RG5 Finding their attitude towards cleanliness and their expectations for the smart floor cleaner.

2.1.2.2 Research question

Direct context

RQ1 What is the use of the current bathroom from a physical point of view?
RQ2 What is the current cleaning from a physical point of view?
RQ3 What is the use of the future bathroom from a physical point of view?
RQ4 What is the future cleaning from a physical point of view?

Indirect context

RQ5 How is the use of the current bathroom from a cultural point of view?
RQ6 How is the current cleaning from a cultural point of view?
RQ7 How is the use of the future bathroom from a cultural point of view?
RQ8 How is the future cleaning from a cultural point of view?

2.1.2.3 Methods

Liturature and website research
Literature and website researches were done throughout the research for knowing the direct context, and the the development of the bathroom in the history of China and the Netherlands.

Observation
An observation research was done by observing the real and the photos of Chinese and Dutch domestic bathrooms, in order to collect and sort out the fitments and the contaminants of the direct context.

Context mapping
A complete context mapping session about the bathroom usage and cleaning habits was done with two Chinese and two Dutch target users to have a general understanding of the indirect context, as well as gaining sources for the later questionnaire. Besides, a collage-based interviews about their attitude towards bathroom cleaning was done with eight target users.

Questionnaire
Online questionnaires were spread to 30 Chinese and 21 Dutch target users in order to gather more data about their cleaning habits, expectations, and attitude towards smart products, and to roughly compare the differences between Chinese and Dutch users. A laddering interview about their pain point when cleaning the bathroom was done in the meanwhile.

2.1.3 Direct context

Smart homes have been mostly treated as homogeneous environments where each room is distinguished by the activities performed there but not by any fundamentally different basic parameters for systems to operate in. [2] However, at least for bathroom environments, things like liquid water and humidity challenge these assumptions. In this aspect, we analyzed the current bathroom usage and cleaning related elements that form the physical working environment. The findings were summarized as conditions and expected experience, which can be found at the last of this part. How they contribute to the envisioned product can be found in 2.2.5 - conclusion.

2.1.3.1 The use of the current bathroom from a physical point of view

A. High temperature and humidity

The temperature range in the bathroom is from 20 °C to 28 °C, while it is 30 °C to 50 °C when taking a bath [3]. The relative humidity in the bathroom is from 20% to 90% [3]. The high humidity level at bathroom (higher than 50%) can lead to condensation in electronics, on screens, capacitive surfaces, and sensors. [2] To sum up, the instant changing humidity and temperature is a characteristic of the bathroom environment. Besides, considering the high humidity level, the envisioned product should be waterproof.

B. No sufficient illumination

In Chinese Domestic Bathroom Standard and Dutch building Decree & House Guide, a bathroom does not belong to the residence area. There are no requirements for the entry of daylight for the bathroom and there is no obligation to have a window in the bathroom. [4, 5] Thus, the insufficient illumination in the bathroom may influence the operations.

C. Small size

The Chinese domestic bathroom standard [4] stipulates that an entire bathroom with two with bathtub/ shower and toilet should be at least 2.5 sq.m, with one should be at least 1.1 sq.m. The Dutch house guide [5] stipulates that a bathroom with shower/bathtub should be at least 1.6 sq.m, and with a toilet should be at least 2.6 sq.m. Thus, the size of the bathroom is small.

2.1.3.2 The current bathroom cleaning from a physical point of view

A. Narrow places and corners

The layouts vary from bathrooms to bathrooms, and it is not possible to study all the bathrooms. In this project, we chose 4 typical layouts provided by Chinese domestic bathroom standard [4] to discuss.

From Figure 6-9 (unit: mm), it can be seen that the flooring sizes are small. Moreover, the gaps between

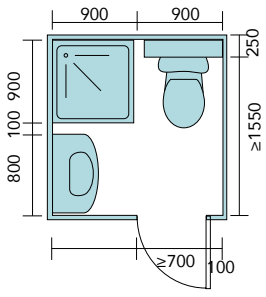


Figure 6. Basic bathroom with shower cubicle

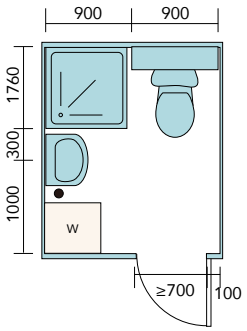


Figure 7. Bathroom with washing machine

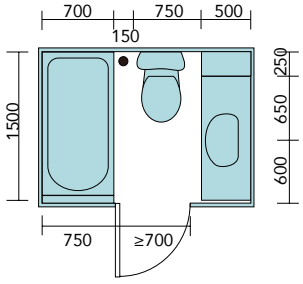


Figure 8. Basic bathroom with bathtub

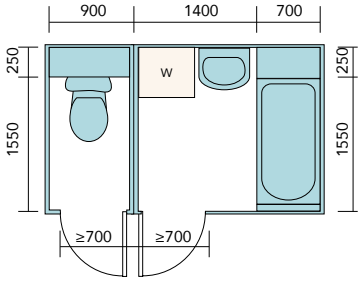


Figure 9. Joint bathroom

the furniture form a lot of irregular narrow spaces and corners which are hard to reach.

B. Fitments

Considering the relation with the floor while cleaning, the fitments are divided into four categories:

Fixed: fitments which are fixed on the floor and the surface is in direct contact with the floor, such as the three basic fitments (shower/bathtub, sink, toilet).

Movable: fitments which can be moved away while cleaning the floor, like the trash can, mat, etc.

Dangling: fitments which do not directly contact with but close to the floor, such as shelves or clothes basket.

Others: fitments which are far away from the floor and is not in any contact with the floor. They will be put on the surface of shelves or other platforms, or hung on the walls.

There are many fitments and articles in the bathroom. When focusing on floor cleaning, only the movable and dangling fitments need to be considered.

For the movable fitments (Figure 10), they need to be temporarily moved away from the floor during the cleaning process. For the dangling fitments (Figure 11), the floor beneath them should be cleaned. Thus, the envisioned smart cleaner is supposed to move through the legs or the bottom of these fitments.

C. Contaminants composition

The common contaminants on the floor were divided into the following categories based on the cleaning methods:

The contaminants can be swept: The contaminants which are dry and do not stick on the floor, like dry hair, dust, and toilet paper, can be easily swept.

The contaminants can be mopped: This category includes puddles, water stain, and foam which can be cleaned by a piece of damp cloth or mop.

The contaminants need to be scrub: The contaminants which are stuck on the floor, such as soap scum, wet hair, mold, and furring, need to be rubbed hard.

Other contaminants: The results of user research showed that some people worried about invisible mold and bacteria.

2.1.3.3 The future bathroom usage & cleaning from a physical point of view

A. Simple

As for their expectations for the bathroom, both groups want it to be as simple as possible (27/31 of Chinese, 16/20 of Dutch), and only contains the basic fitments. The main reason is that they regard the bathroom as a functional place for bathing. Most of them will not spend too much time in the bathroom, nor will they expect any playful functions. In other words, they do not want distractions in the bathroom. In addition, the simple bathroom is more integrated, making it look neat and easier to clean.

B. Natural

Most of the participants prefer a natural and manual bathroom rather than a technical and automatic bathroom (18/31 of Chinese, 19/20 of Dutch). The main factor for choosing the natural bathroom is that it looks more relaxed. They want their bathroom to be fresh and cozy. Comparing with the natural bathroom, the technical bathroom is too cold and fragile. Another reason is the distrust of technology. For Dutch participants, some of them also said they did not see the necessity of having smart products in the bathroom.

For the other 13 Chinese who prefer the technical bathroom, the only reason is that it is more convenient.

Figure 10. A movable fitment in the bathroom

Figure 11. A dangling fitment in the bathroom

2.1.4 Indirect context

In this aspect, the context was studied from a cultural point of view. The target users were defined as Chinese and Dutch young adults. Then, we studied how the use and cleaning of the current bathroom were and how the future bathroom usage and cleaning would be. The outcomes were summarized as the expected functions and experience in the 2.2.5 - conclusion.

2.1.4.1 Target users

The behavior and expectations of different user groups are different. In order to analyze a certain group's behavior, we need to define a target group.

The target user has been defined as young adults for the following reasons: Based on a pwc research, one-third of the young adults (18-34) own a smart home device. Besides, 18% of them plan to own it the next year, which is the highest of all ages [10]. A GfK research also shows that young adults are more willing to try emerging electronic products [11]. As a result, the university students and the new employees have been selected as target user, because they are one of the main consumers of the smart product. In addition, they are easier to reach from a development point of view.

2.1.4.2 The use of the current bathroom from a cultural point of view

The usage habits include the usage time and tasks have done in the bathroom. The results are based on a contextmapping session, the details of which can be found in appendix A-Context mapping.

A. Usage time point and duration

As can be seen from the figure 12 that: All the participants will go out to work or study during workdays, so the usage times during workdays are less than weekends. The peak hours on workdays is in the morning (from 8 am to 9 am) and at night (from 8 pm to 10 pm). On weekends, the bathroom will be busy almost the whole daytime. The free time is from about 1 am to 7 am. People will go to the bathroom several times randomly during the day, but the whole duration that stays in the bathroom is not long.

To sum up, on workdays, the bathrooms will be used frequently in the morning and at night, but will not be used during the day and the early hour of the morning. Although they will use the bathroom several times a day, the whole residence time is short.

B. Daily activities in the bathroom

As a functional space, participants only used the bathroom when they need to do the specific tasks that include taking a shower, going to the bathroom, and others (brushing teeth, washing face, shaving, combing hair, etc.). They will not use the bathroom during other time. Besides, privacy concerns might play a bigger role for many users in the bathroom than they do for other rooms such as the kitchen or the living room [2]. Therefore, camera-based vision imaging cannot be used in the bathroom when considering the ethical issue.

In conclusion, the participants regard the bathroom as a functional place for specific tasks. The privacy of these tasks should be taken into consideration.

2.1.4.3 The current cleaning from a cultural point of view

The cleaning habits can be represented by the cleaning time, the cleaning tools, and the pain points they found during cleaning. The result below is based on the answers to the questionnaire and the laddering interviews. The details about the questionnaire can be found in appendix B-Queestionnaire.

A. Incidental and scheduled cleaning

For both groups, above half of the participants will clean the bathroom on schedule (19/31 of Chinese and 13/20 of Dutch). A vast number of Chinese (24/31) will clean when they think the floor is dirty, while about 6/20 Dutch will do it. Thus, there are two main cleaning time: incidental cleaning and scheduled cleaning. For different types of cleaning, the range of cleaning is also different. Normally, the participants mentioned that they will only clean the dirty area in a incidental cleaning, carefully clean the entire ground during a regular cleaning.

B. Quick and convenient tools

The mop is the most frequently-used cleaning tool for both groups. For Dutch, half of the participants also chose cleaning agents (10/20), while 12/31 Chinese participants chose that. Quick and convenient are the main reasons for them to choose the tools (Both Chinese and Dutch are more than half). Besides, one-third of the participants also mentioned that these

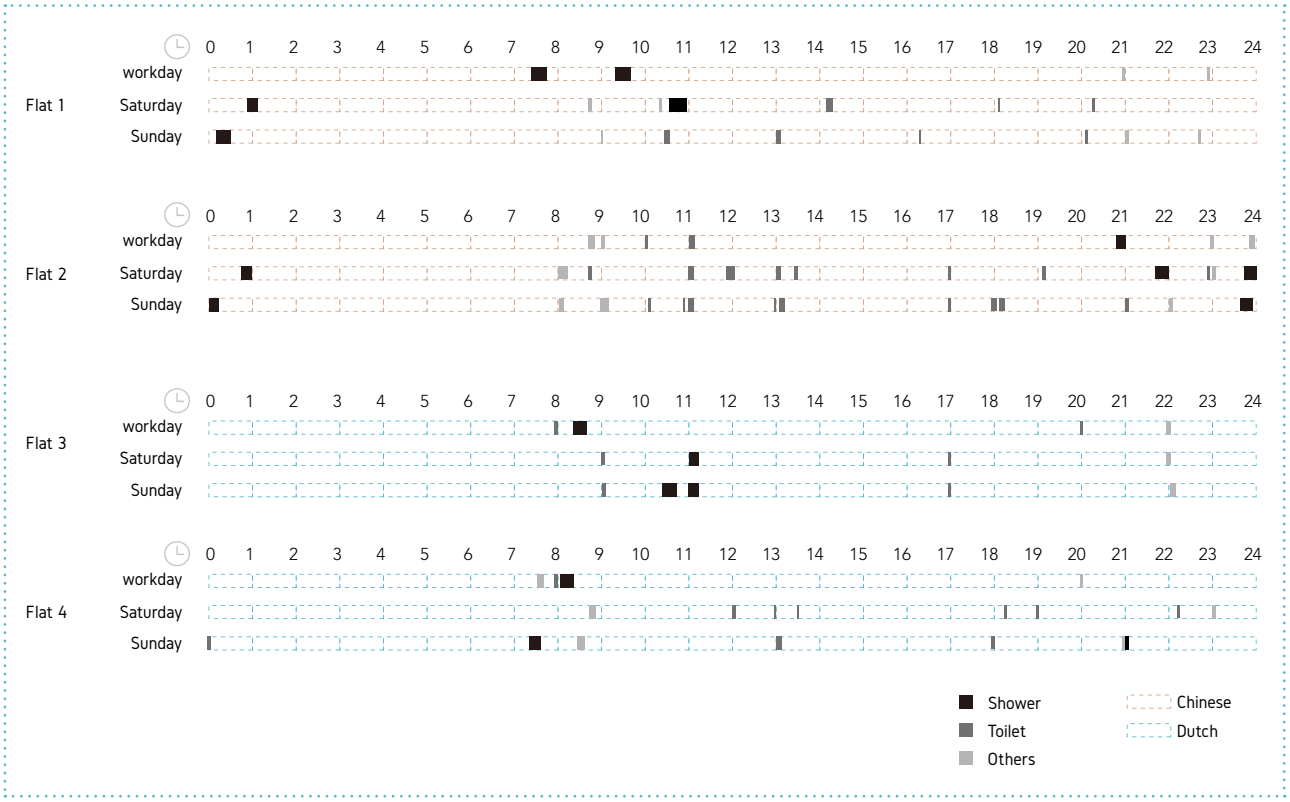


Figure 12. Bathroom usage time of the four participants

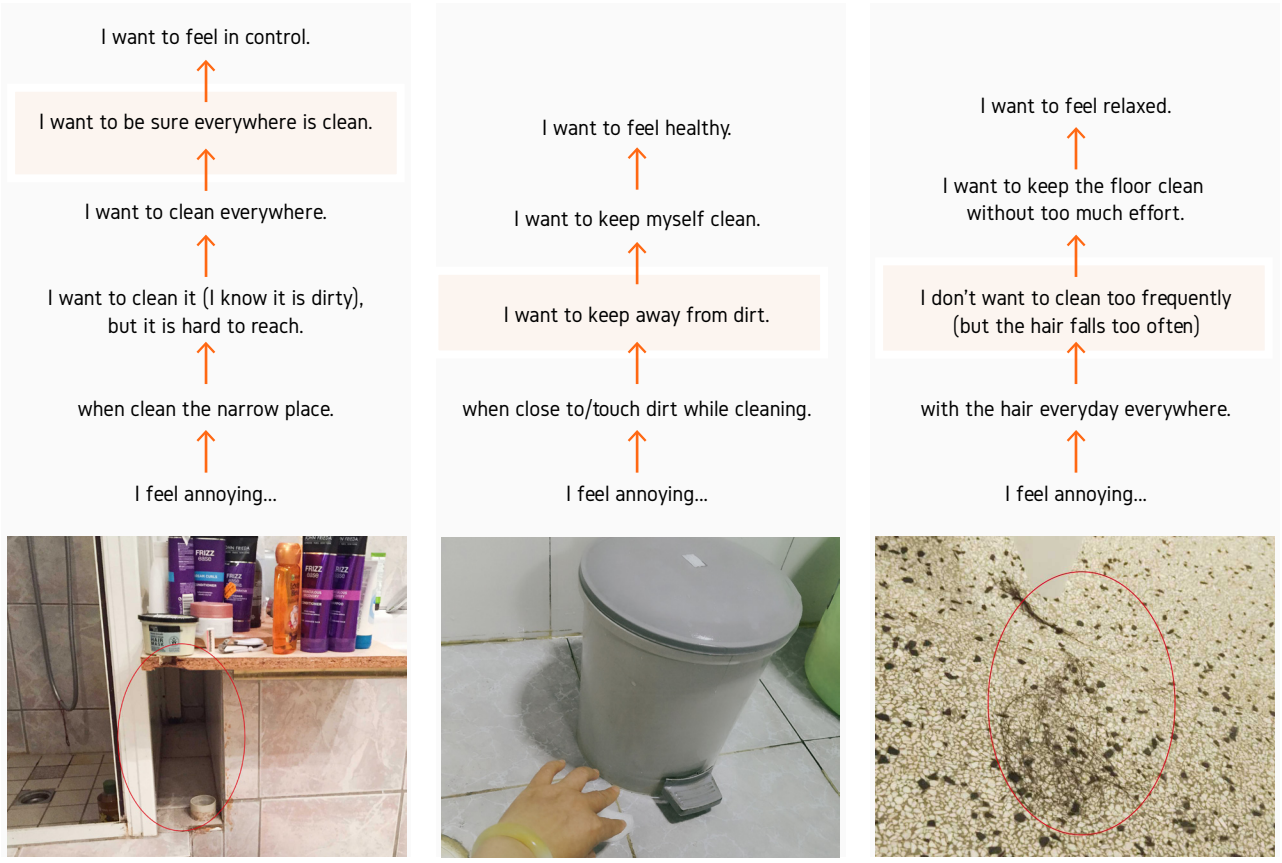


Figure 13. Laddering reasons behind the pain points

tools could clean thoroughly. However, cleaning the mop is a troublesome issue since the traditional mop is heavy when full of water. Therefor, some participants use disposable wet wipes to replace it.

C. Pain points and the reasons behind

When clean the bathroom floor, the most annoying thing for both groups is to clean the narrow places (21/31 of Chinese and 11/20 of Dutch). The second is close to or touch dirt while cleaning. For Chinese participants, they also do not want to deal with the trash after cleaning (19/31). Another annoying situation is to deal with the hair on the floor (18/31 of Chinese and 6/20 of Dutch).

Laddering interviews were done to understand the reasons behind these pain points, which can be seen in Figure 13. For each pain point, we selected one reason that could be used as a design point: For people who want to clean the narrow places, the point is to make sure everywhere has been cleaned. People who do not want to touch dirt are concerned about keeping away from dirt. And for those who do not like cleaning hair, they want to keep the floor clean without too much efforts.

2.1.4.4 The future bathroom usage & cleaning from a cultural point of view

A. Attitude towards cleanliness

The final objective of this smart cleaner is to provide a clean bathroom floor for the target users. However, the meaning of bathroom cleanliness is different from person to person. In this part, we asked 8 target users based on a collage of pictures about clean, in order to gather some inspirations of how they think about domestic bathroom cleanliness. Since the number of participants is not enough to provide a quantitative solution, the finding will only be used for inspiration. The detailed research can be found in appendix C-Value towards cleanliness.

The findings of the research gave the following inspirations:

I1 A space that has been cleaned does not mean it is clean. People may think about whether the cleaning tool is clean or if it has been cleaned properly.

I2 The disposable object represents different meanings. Some participants regarded it as a personal item or the first-time item, which means it is clean. However, it is not clean from the environment-friendly perspective.

In general, I1 indicates that the bathroom floor has a chance to be a clean place, but it is important to make the cleanliness reliable. I2 indicates that disposable goods might be able to use as part of the product to make people feel clean, but the whole product should not be disposable from an environmental-friendly perspective.

B. Expectations for the smart bathroom floor cleaner

a. Attitude towards bathroom-related smart products

The result of the questionnaire shows that 11/31 of Chinese people have never used a bathroom-related smart product, but for the Dutch, the number is 17/20. It is safe to say that Chinese users are more likely to accept the smart products and would like to use it, while Dutch users are not. For not using the smart bathroom-related product, the participants gave the following reasons:

- It is too expensive.
- They do not trust it, especially in the bathroom.
- It will break the existing bathroom environment.
- The current product is good, they do not see the necessity.

Therefore, the factors that may influence the use of bathroom-related products include price, convenience, privacy issues and practicality.

b. Expected features of the smart floor cleaner

The most attractive features that both groups want to add to their future cleaning tools are the same, which include self-cleaning, thoroughly dirt cleaning and bacteria detection. However, when considering buying a cleaning product, the most concerned points for these two groups are different. For Chinese participants, the triggers include easy to use (18/31), time-saving (16/31), and self-cleaning (16/31). For Dutch participants, they are water-saving (14/20), easy to use (12/20), and energy-saving (10/20). To sum up, both groups expect the future bathroom cleaning tool can be more automatic, can thoroughly clean the contaminants, and easy to use. Dutch users concerned about environmental friendly issues. But for Chinese users, saving time and effort are the most concerned.

2.1.4 Conclusion

This chapter has analyzed the context of the interaction. The elements in the direct and indirect context could be summarized into the following three parts: the ambient conditions, the cleaning related concerns, and the expectations. The correspondence of the researches and the conclusions are illustrated in figure 14.

As for cultural differences, from the researches, we cannot find a great distinction about the usage and cleaning habits between the Chinese and Dutch participants. The main differences are the expected experience, which is their attitude towards smart products and the expectation for the future product.

Ambient conditions

- Rapid temperature and humidity changes
- High humidity level
- Insufficient illumination
- Small space
- High privacy

Cleaning related concerns

General requirements for bathroom cleaning tools:

- Easy to use
- Quick and convenient
- Affordable price

Expected functions for bathroom cleaning tools:

- Clean different contaminants
- Obstacle avoidance
- Reach narrow places and corners
- Different starting logics: Incidental & scheduled cleaning
- Stop operating when human appears
- Handle the dirt after cleaning
- Cleaning monitor

Expected experience

The expected experience comes from the participants' attitude towards cleanliness when sharing a bathroom with others, and their expectation for bathroom usage and cleaning.

- Trustworthy
- Effortless

Extra for Chinese users

- High interest in smart products

Extra for Dutch users

- Practical, conservative for smart products

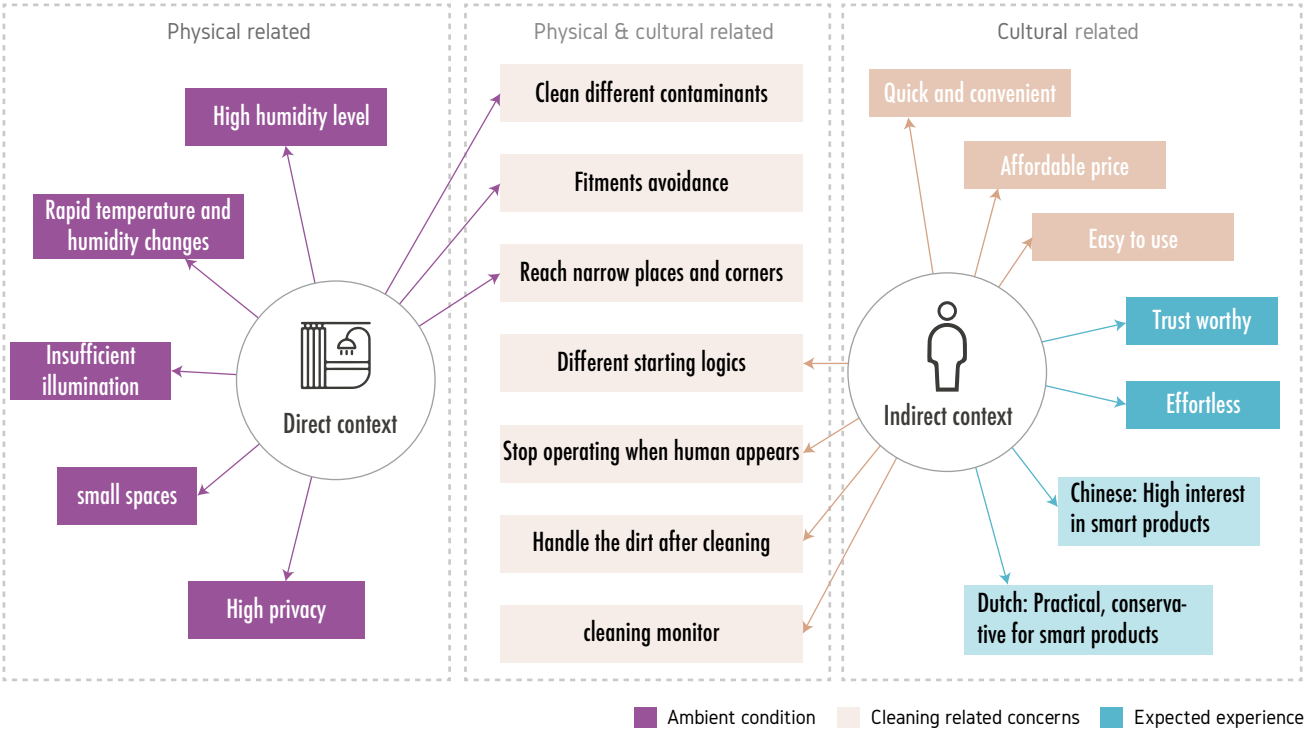


Figure 14. Summarized conclusion of the context aspects

2.2 TECHNOLOGY ASPECTS

2.2.1 Objective and approach

After analyzing the expectation and the special conditions of the context, the aim of this part is to find suitable technologies can be used to meet the expectations, and be suitable for the context.

The research contains three parts: 1) the existed products that have similar functions. 2) the technologies that can be applied to the needed functions. 3) the principles of cyber-physical systems (CPSs) that supplement and organize the technologies and functions. Literature and website researches were done throughout the analysis.

2.2.2 Smart bathroom cleaning products

2.2.2.1 Floor cleaning products

Smart vacuum robots, often called robovac, have intelligent programming and vacuum cleaning system, providing autonomous vacuum cleaning service. Some companies already had a well-developed technique and launched products like Roomba (iRobot, 2002) and Neato XV (Neato, 2010) which are efficient enough to clean contaminations like dust, hair, and other dry shavings. Apart from the physical product, a smart vacuum robot usually combines a mobile app to achieve expanding functions like timing cleaning or targeted space cleaning. However, this form of the product cannot effectively remove the damp or stubborn stains. As mentioned in the bathroom environment research, the contaminations in the bathroom contain soap scum and sewage which cannot be vacuumed, which creates a challenge for the smart vacuum robot.

Smart mopping robots also have intelligent programming system and expanding app, like Braava (iRobot, 2012). However, comparing with the sweeping robot, it has a small cleaning pad and a water tank, instead of the vacuum cleaner. With the cleaning pad, it can effectively remove the damp and stubborn stains, and soak up the sewage. However, since it is incapable of vacuuming lots of solid contaminations, the dirt which cannot be soaked will be spread across the floor and cause secondary pollution.

Smart vacuum & mopping robots combine the main functions of the above two products and provide vacuuming and mopping service. This product like Roborock (Xiaomi, 2017) has a vacuum cleaner and a cleaning pad with a water tank, which makes it be available to vacuum and mop at the same time. The cleaning map is placed behind the suction mechanism, which effectively avoids the secondary pollution while cleaning. However, the vacuuming and mopping functions are executive the same routine, but the best cleaning way is to put more efforts on the dirtier place.

Smart dusting robots only provide dusting service. Comparing with vacuum robot, this form of robot, like Mopet (CCP, 2015), has no suction mechanism, but a microfiber cloth under its body to sweep the small pieces of dirt like duct, hair, and crumbs. Although the function is very limited, it is much smaller than the above smart floor cleaners, so it is compact enough to squeeze into tight spaces around fixtures at home. Also, it is much cheaper than other smart cleaners.

2.2.2.2 Toilet cleaning prooducts

Toilet cleaning robot is a new product on the market. It is essentially a robotic arm which moves a customized toilet brush to clean [5]. Giddel (Altan Robotech, 2018) is advertised as the first toilet cleaning robot. After putting this robot on the toilet and pressing start, the toilet bowl will be automatically cleaned by the robotic arm. The device is good at cleaning the inside of the bowl, but it cannot scrub the seat. Its high price ($ 500) might be another reason that stops users to buy it. SpinX (2017) is another toilet cleaning robot which is said can not only clean the toilet bowl but also the toilet seat. However, this startup project is still at the concept stage and has not been put on the market yet.

2.2.2.3 Bathtub cleaning products

A **self-cleaning bathtub** can clean itself after each usage. Yupatio is a smart bathtub designed by a Japanese company Noritz in 2016. After a shower, the user only needs to close the lid and press the switch, then hot water and detergent will be spill out from the central spout to clean the soap scum that on the interior wall of the bathtub. However, this self-cleaning function is not thoroughly enough, because the edge or the tap of the bathtub will not be reached. Besides, users have to pay for the whole expensive product though they only need the cleaning function.

2.2.2.4 Other cleaning products

Self-cleaning public toilet, like Sanisette in France and eToilet in India, provide a self-wash and dry toilet. Toilitech designed two public toilets PLUS (2015) and SMART (2018) which guarantee the high level

of hygiene and disinfection of the toilet at each use [26]. The SMART toilet cleans the toilet bowl and the surrounding walls by a concealed spray arm, while the floor is cleaned with spray water and disinfectant by a floor-integrated high-pressure nozzle system. The PLUS toilet uses a similar cleaning and drying system as the SMART toilet, accompanies with a floor wiper system to remove all debris from the toilet floor.

There are also many cleaning robot conceptions. For example, designed by Adrian Perez Zapata, Mab is an automated cleaning system that consists of hundreds of flight mini-robots. With those mini robots, it can fly to every corner and clean up all surfaces. Jell ball (Juan Lee, 2013) is another cleaning robot concept that is using eight nanorobots in gelatin to clean dust based on a jell surface tension principle.

Figure 15 summarized the functions that the current products have. The technologies of these functions have been discussed in the next part.

Smart vacuum robots

- Clean different contaminants
- ✓ Obstacle avoidance
- Reach narrow places and corners
- Cleaning time
- ✓ Timely/regularly
- Stop operating when people appear
- ? Dealing with dirt after cleaning
- ✓ Properly cleaning

Toilet cleaning robot

- ? Clean different contaminants
- Obstacle avoidance
- ✓ Reach narrow places and corners
- Cleaning time
- ✓ Timely/regularly
- Stop operating when people appear
- ✓ Dealing with dirt after cleaning
- Properly cleaning

Smart mopping robots

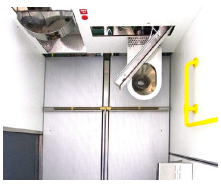
- ✓ Clean different contaminants
- ✓ Obstacle avoidance
- ? Reach narrow places and corners
- Cleaning time
- Timely/regularly
- Stop operating when people appear
- Dealing with dirt after cleaning
- ✓ Properly cleaning

Self-cleaning bathtub

- Clean different contaminants
- Obstacle avoidance
- Reach narrow places and corners
- Cleaning time
- ✓ Timely/regularly
- Stop operating when people appear
- ✓ Dealing with dirt after cleaning
- Properly cleaning

Smart vacuum & mopping robots

- ✓ Clean different contaminants
- ✓ Obstacle avoidance
- Reach narrow places and corners
- Cleaning time
- ✓ Timely/regularly
- Stop operating when people appear
- Dealing with dirt after cleaning
- ✓ Properly cleaning

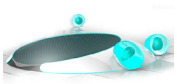


Self-cleaning public toilet

- ✓ Clean different contaminants
- Obstacle avoidance
- ✓ Reach narrow places and corners
- Cleaning time
- ✓ Timely/regularly
- Stop operating when people appear
- ✓ Dealing with dirt after cleaning
- Properly cleaning

Smart dusting robots

- Clean different contaminants
- ✓ Obstacle avoidance
- ✓ Reach narrow places and corners
- Cleaning time
- Timely/regularly
- Stop operating when people appear
- Dealing with dirt after cleaning
- Properly cleaning



Future cleaner conceptions

- ? Clean different contaminants
- ✓ Obstacle avoidance
- ✓ Reach narrow places and corners
- Cleaning time
- Timely/regularly
- Stop operating when people appear
- Dealing with dirt after cleaning
- Properly cleaning

Figure 15. Functions of the current products

2.2.3 Smart cleaning product technologies

In chapter 2.1.4 - Context aspect conclusion, the cleaning related concerns corresponding to specific functions. Apart from these functions, basic functions of smart floor cleaners such as path planning and back charging alson need to be taken into consideration. Figure 16 shows the required functions of the envisioned product.

2.2.3.1 Detecting contaminants

With a dirt detecting function, the cleaner will be able to put more efforts on a more dusty spot automatically, in order to save time. The common dirt detection includes the following methods:

A dirt sensor circuit (iRobot, 1997) with an audio detector or infrared sensor. The circuit provides amplification of the audio/light signal, a pulse stretcher, sensitive selection of non-linear characteristic and visual signal means to indicate high or levels of dirt concentration. [12]

A piezoelectric debris sensor and an associated signal processor responsive to debris strikes enable an autonomous or non-autonomous cleaning device to detect the presence of debris and in response, to select a behavioral mode, operational condition or pattern of movements, such as spot coverage or the like. [13]

Vision-based dirt detection is an emerging technique for autonomous cleaning robots. Andersen et al. [5] developed a visual cleaning sensor for autonomous cleaning robot based on computer vision and high-power light-emitting diode. Bormann et al. adopted a spectral residual image filter for detecting the dust and dirt on a floor image, where maximal filter response and minimal filter response of the different floor pattern are used to fix dirt thresholds. [14]

2.2.3.2 Cleaning different contaminants

The common contaminants on the bathroom floor consist of the following parts. The most suitable cleaning method for each contaminant is different.

A. The dry contaminants

The contaminants which are dry and not stuck on the floor can be easily vacuumed. Besides, if the amount is not large, electrostatic vinyl paper, cleaning gal/hydrogel and microfiber cloth can also be used to

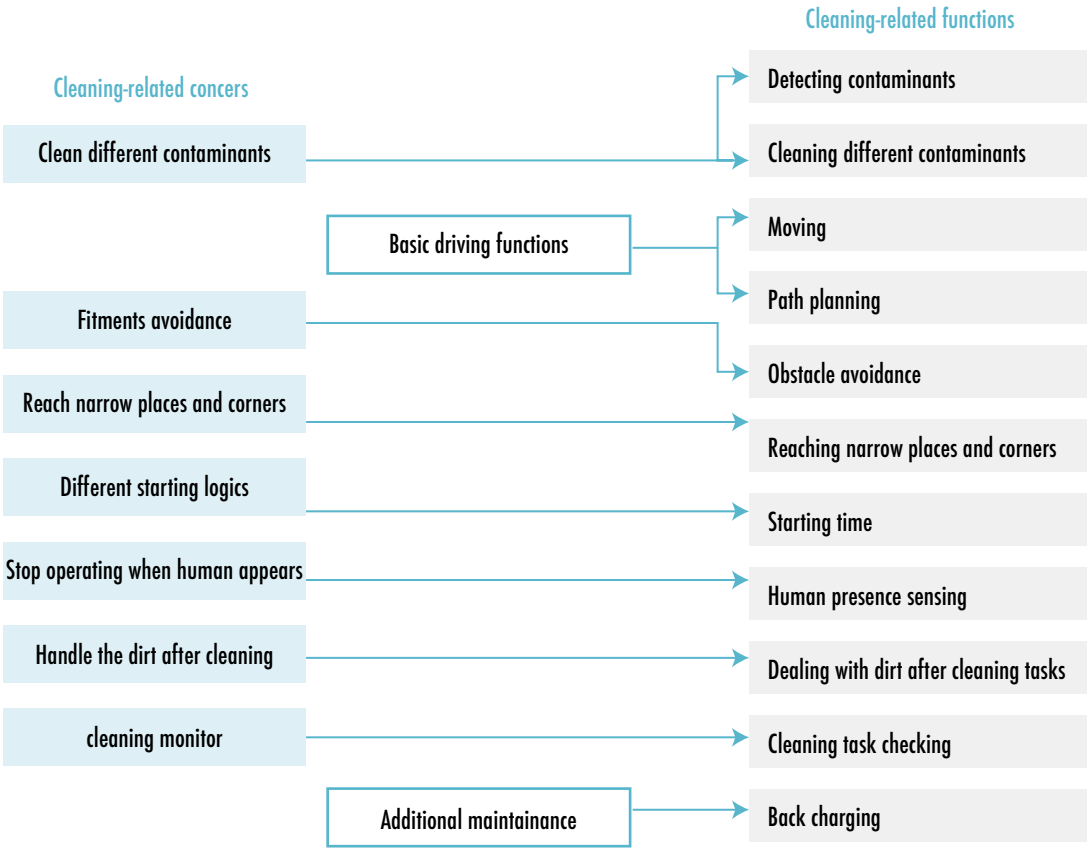


Figure 16. Required cleaning functions of the envisioned product

clean them. However, mopping or brushing is not good cleaning methods for them, since these contaminants might spread across the floor and cause secondary pollution.

B. The contaminants can be mopped

This category includes puddles, water stain, and foam which can be easily cleaned by damp cloth pad or mop. However, they cannot be easily vacuumed, swept, or brushed.

C. The contaminants can be brushed

The contaminants which are stuck on the floor, such as soap scum, wet hair, mold, and furring, need more efforts to clean. Scratching by a robotic arm or mopping several times are feasible solutions, while vacuuming or slightly mopping might do not work. Besides, detergents will be used together with water to clean these contaminants thoroughly.

2.2.3.3 Moving

For most of the floor cleaning robots, the moving systems consist of universal wheels, main wheels, wheel motors, and motor sensors. Some single function dusting robots rely on rolling to move.

2.2.3.4 Path planning

The best cleaning path should follow these principles: First, the simpler, the better. Second, it should clean all the open spaces. Third, the repetition of cleaning for the same place should be low. Forth, the dirtier place should be cleaned more times.

At present, different technologies are used to achieve navigation and path planning, such as a laser sensor for distance ranging, camera for visual imaging, NorthStar navigation system, etc. However, different environmental conditions will cause significant interference to the sensors. For example, the navigation relies on the camera will invalidate in a dark environment.

2.2.3.5 Obstacle avoidance

In order to avoid obstacles in the movement, a group of sensors is used, such as a crash sensor and an infrared radar sensor in front of the robot, an infrared wall following sensor around the robot, a floor tracking sensor and several cliff sensors at the bottom.

For limiting the range of movement, virtual walls such as infrared beams or magnetic strips are used (iRobot, 2010). Besides, the floor cleaning robots are usually equipped with a mobile app to set the cleaning range.

2.2.3.6 Cleaning the corners and narrow spaces

The bathroom is not large in general, together with many narrow spaces and corners which are hard to reach. The current smart vacuum robots use a double/ single side brush to clean the dirt in the corner. However, in chapter 2.1.3-Direct context, we could see that there are narrow spaces which are smaller than 15 cm, but smart cleaning robots are usually bigger than that. For example, the roborock sweeping and mopping robot (Xiaomi, 2017) is at 27 cm in diameter and 9.6 cm tall, and the Braava mopping robot is a rather small unit, coming in at 24 cm in length, 21.5 cm wide, and 8 cm tall.

For other cleaning products which have smaller than the normal cleaning robot, such as dusting robot (dusting ball) and toilet cleaning robot (robotic arm), they only have a specific function. Besides, another concept for the future cleaning robot is using a large number of honeybee robotics to clean all the hard-to-reach corners(Mab, 2013).

2.2.3.7 Cleaning time

In order to satisfy different cleaning habits, the envisioned product is supposed to start operating timely or regularly. Currently, the most common method for starting the cleaning task is pressing a physical button. Besides, the matched mobile app can be used to perform more complex functions, such as regular cleaning and spot cleaning.

2.2.3.8 Human presence sensing

Since privacy is a big concern when people use the bathroom, the envisioned product needs to stop working when someone is in the bathroom. We cannot find a similar function on the current smart cleaners, but a human presence sensor is used on other smart product to monitor the presence of human.

2.2.3.9 Dealing dirt after cleaning tasks

We summarized some self-cleaning ways mentioned in the above cleaning products. Some smart vacuums use an inner vacuum system to vacuum the dust into a trash bag in the maintenance station. A self ventilation

system is used on some mopping robots to clean the mop pad. The self-cleaning bathtub cleans itself by spilling hot water and detergent from a central spout. The soap scum on the interior wall will be washed away by the high-pressure water. The public toilet uses a spray arm to move all the trashes on the floor, and then a floor-integrated high-pressure nozzle system will clean the whole toilet room floor.

2.2.3.10 Cleaning task checking

The last function that the target users concerned is whether the cleaning task has been completed properly, which can also be called cleaning task checking.

Apart from direct observation with the eyes, users can monitor the cleaning path by the matched mobile app to ensure the cleaned areas. As for cleaning all the contaminants, some of the current smart vacuums use the contaminants detecting system (a dust sensor and an image acquisition module) to complete. However, this system is unable to give direct feedback to users.

2.2.3.11 Back charging

Nowadays, more and more cleaning robots can move back automatically to charge when the battery is low. The technologies of finding the location of the charging port can be infrared sensor, Bluetooth, ultrasonic, or radio wave.

2.2.3.12 Conclusion

Figure 17 shows an overview of the technologies that have been used on the current products, and an initial evaluation based on the context conditions and expectations in chapter 2.1.4 - Context aspect conclusion. Then, the promissing technologies are selected and shown in chapter 2.2.5-Technology aspects conclusion.

FuctionT	echnology	Advantages	Disadvantages
Detecting dirts	audio detector infrared sensor	Mature technique	Works at close range
	vision-based dirt detection	High precision	High cost Unknown reliability
Cleaning dirts	vacuum system	Inhale a lot of dust	Big size
	microfiber cloth	Low cost	Hard to clean
	electrostatic vinyl paper	Low cost & convenient No need to clean	Not eco
	cleaning gal/hydrogel	Low cost Deal with multiple dust	Unknown reliability
	damp cloth pad	Low cost	May cause secondary pollution
	robotic arm (brush)	Can clean stubborn stain	Limited operating range
	mopping several times	Low cost	Low efficiency
Moving	Rolling	All-round	Hard to control
	moving wheel	Large operating range	Need lots of sensors
	robotic arm	All-round	Limited operating range

Figure 17-1. Overview and initial evaluation of the related technologies

FuctionT	echnology	Advantages	Disadvantages
Path loanning & navigation	laser sensor	Mature technique	High precision
	visual imaging (camera)	High precision	Low privacy Need illumination
	northstar navigation system	High precision	High cost Patent protection
Obstacle avoidance	sensor system (crash sensor, etc.)	High precision	
	virtual walls	Low cost	Limited range Extra effort
	mobile app	Flexible	Extra effort
Reaching narrow places/corners	side brush	Low cost	Limited range
	dusting ball	Low cost Flexible	Hard to clean
	robotic arm	All-round	Limited operating range
	honeybee robotic	Flexible	High cost Unknown reliability
Starting time	physical button	Low cost	Limited range
	mobile app	Flexible	
Stopping	human presence sensor		
Dealing dirt	vacuum system	Efficient	Big size Only cleaned limited dirt
	self ventilation system	Can clean mop	Big size
	floor-integrated nozzle system	Efficient	Need to transform the entire floor
Proper cleaning	mobile app	In time	Cannot detect dirt
	detecting system		No direct feedback
Back charging	bluetooth	High precision	High cost
	infrared sensor	Mature technique	Limited range
	ultrasonic/radio wave	High precision	High cost

more suitable less suitable

Figure 17-2. Overview and initial evaluation of the related technologies

2.2.4 Cyber-physical systems principles

In this project, a cyber-physical system is formed by the bathroom environment, the users, and the smart cleaner. After analyzing the related technologies which might be satisfied the expectations, several CPSs principles have been applied to integrate the possible technologies, and to find new inspirations to implement the envisioned product.

2.2.4.1 CPSs implementation technologies

In a cyber-physical system, every system is regarded as a structure of cyber components and physical components, and a synergic system that couples the pure cyber and physical system. [17] In this project, the overview of the related technologies can be seen in Figure 18.

2.2.4.2 Event-orientated control

When designing a CPS, continuous physical processes can be converted into a queue of discrete events. [17] Thus, the whole operation of the system can be modeled as a discrete-event system. In this project, the operation of this smart cleaner can be converted into major events in Figure 19. For each event, the start time and the duration need to be paid attention.

2.2.4.3 Levels of automation

We are of the opinion that CPSs can be called intelligent only if they have reached the level of intelligence, autonomy, symbiosis, and sociality that is comparable with that of human individuals and communities. [18] However, with the current technologies we cannot reach a fully autonomous intelligent level. Therefore, in the developing process of CPSs, a conceptual advancement model was created to introduce the meaning of different levels of intelligence. The levels of automation (LoAs) are one of the representations of the conceptual advancement model in the context of engineered technical systems [18]. The relationships and the characters of humans and systems are representing as a structure of strata. [18] (Figure 20)

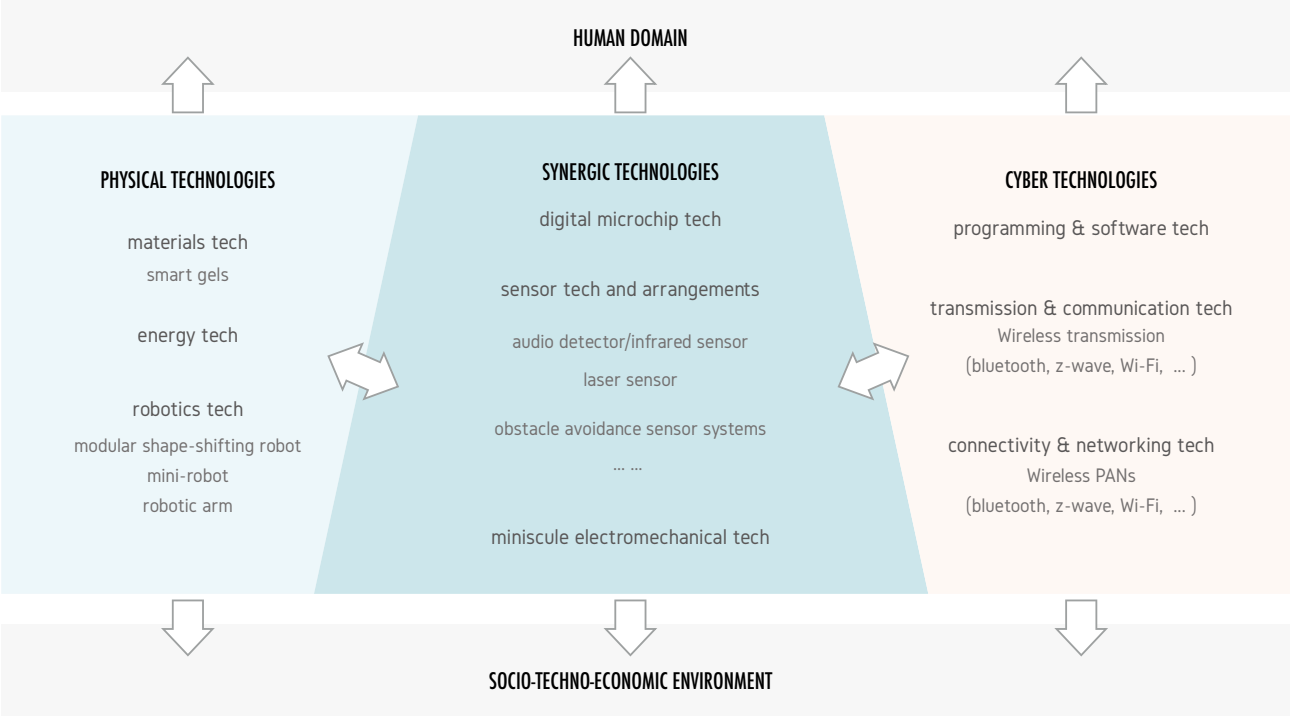


Figure 18. CPSs implementation technologies

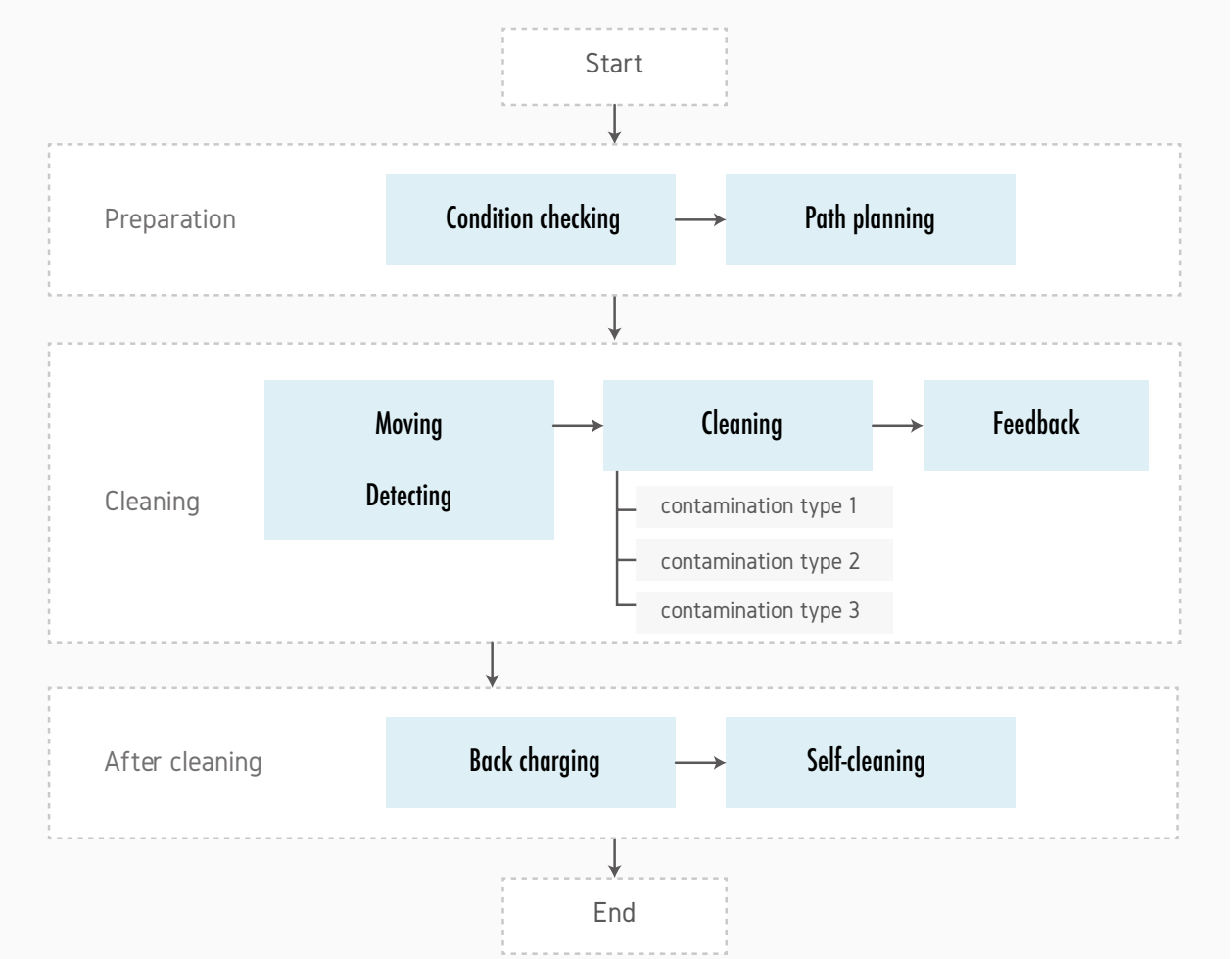


Figure 19. Operation events

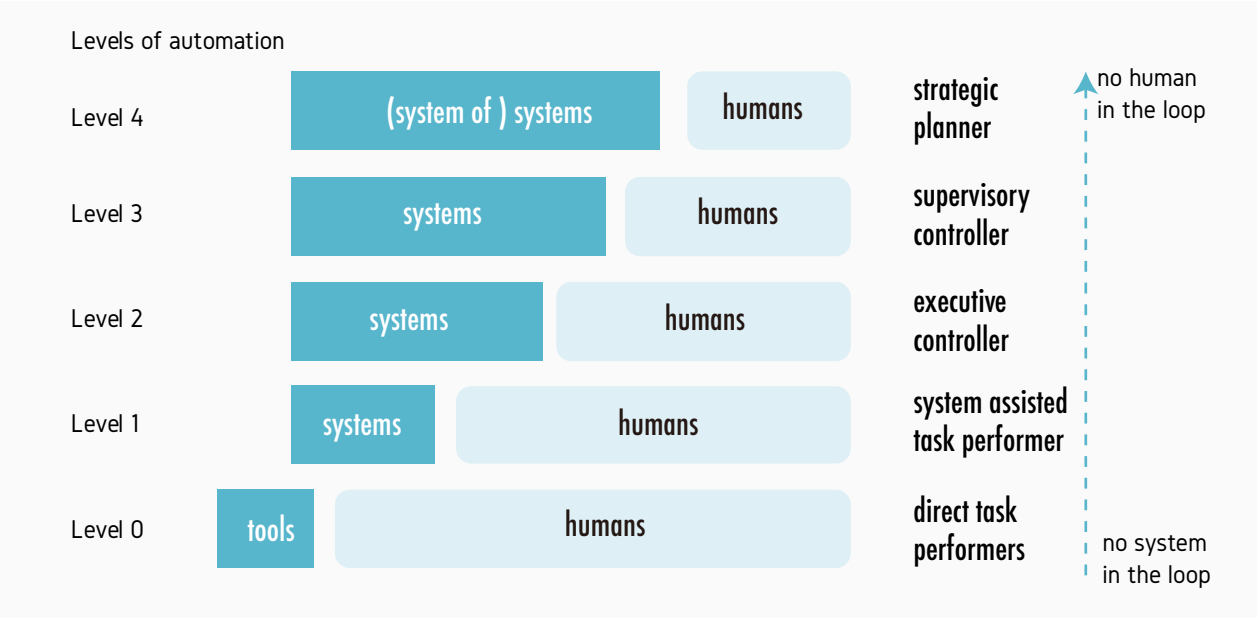


Figure 20. Levels of automation interpreted in the context of engineered technical systems

2.2.5 Conclusion

This aspect has analyzed the required technologies that can make the envisioned product work, also the CPSs principles might be used to build the smart system of bathroom, human, and the device.

Since the smart system is complex, we applied 2.2.4.2-Event oriented control to seperated the huge and complex cleaning event into a series of single events. Then, the promissing technologies (details in 2.2.3-Smart cleaning product technologies) of each event were classified based on 2.2.4.1- CPSs implementation technologies. Figure 21 shows an overview of the cleaning events series and the technologies can be used.

Besides, since the focus of this project is the interaction between the user and the product, different levels of intelligent can be used as a starting point of generating different concepts in 3.4-Interaction concepts.

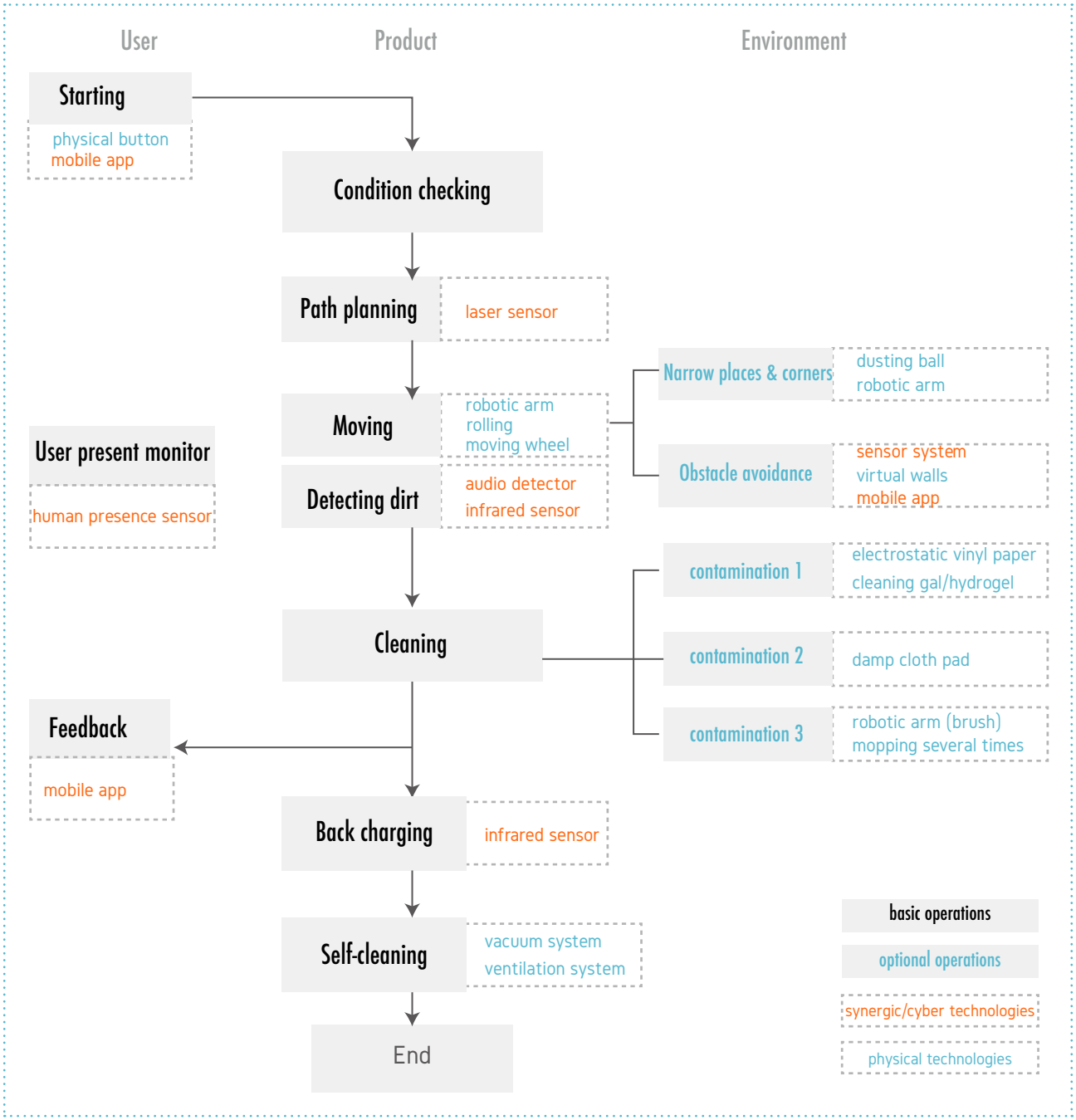


Figure 21. Overview of the related events and technologies

2.3 MARKET ASPECTS

2.3.1 Objective

Apart from analyzing what the envisioned product can provide to the users, and how to realize the desired features, it is also important to know the current market. In the business aspect, the smart product market in China and the Netherlands were analyzed separately, in order to develop strategic planning. In addition, consumer behavior and acceptable price of China and the Netherlands were studied to find how the product should be positioned in the market.

2.3.2 Approaches

Website researches have been done to analyze the smart product market, the directions include 1) the local robot market, 2) the domestic service robot, and 3) consumers' interests toward smart products. SWOT analysis has been applied to understand the industry further and to find strategic opportunities. For studying the consumers, website researches have been done on consumer behaviors.

2.3.3 Smart product market analysis

2.3.3.1 Chinese smart product market

Chinese robot market developed rapidly in recent years. In 2018, the Chinese service robot market has increased about 43.9% year-on-year, which is higher than the growth rate of the global service robot market [20]. The increasing rate of domestic service robots and public service robots is relatively faster than other domains of robot markets [20].

With the development of artificial intelligence and cross integration of multidisciplinary cutting-edge technologies, Chinese domestic robots have gradually developed fruitful and new functions. New products with compact size, friendly interaction, and cost-efficient have emerged, which satisfied the different consumer needs and stimulated the development of the whole market. Based on GfK consumer life report (2018), young adults are more willing to pay for the new domestic products.

Floor cleaning robot as an entering level product of domestic service robot has been developed relatively maturely. In 2018, the market size of floor cleaning robot was about 0.6 billion dollars, which is more than half of the whole consumer robot market [21]. Many Chinese enterprises accessed to this market and developed a variety of products, such as DJ floor cleaning robot (Ecovacs, 2018), and Roborock vacuum and mopping robot (Xiaomi, 2017). Although many international brands entered into the Chinese market, domestic brand Ecovacs is still the most popular brand in China [22]. As for the primary consumers of the floor cleaning robot, GfK (2018) found that the middle-class people who live in developed cities are more willing to pay for the floor cleaning robot.

However, some problems need to be paid attention to. For example, the core technologies need to be improved, and the market development needs to be further regulated [23]. After the rapid developing stage, more efforts should be put on standardization and security aspects. The SWOT analysis of the Chinese market is in Table 1.

2.3.3.2 Dutch smart product market

The big trend in the Netherlands robotic are the new technologies like handling big data, artificial intelligence, etc. [24]. Different companies and departments are active in their specific area of expertise, and there are more and more knowledge holders involved with each other. Cooperation creates a strong foundation for innovation [24]. Now there might be no booming robotics business in the Netherlands, but the knowledge has covered the whole required aspects.

However, the consumer robotic sector is not very present in the Netherlands [24]. Although Philips does sell vacuum cleaning robot, it does not take a leading role in this market compared with other international companies.

Besides, Dutch consumers' interest in Smart Home has declined in recent year. 49% of Dutch people indicate that they are not interested or very interested in Smart Home products, a decrease compared to last year [25].

The most recent GfK data also shows that the most popular smart products are about lighting, energy, and security. Cost remains the most significant barrier to purchase Smart Home products. The SWOT analysis of the Dutch market is in Table 2.

2.3.4 Consumers

2.3.4.1 Chinese consumers

China is in the midst of a consumer revolution. In the past, Chinese consumers cared more about functions and prices, while nowadays the criteria are becoming complex. China's main consumer force is made up of individuals in 20s and 30s [27], which is also the target user in this project. They are generally better educated, tend to save less, and spend more than their parents on entertainment. Most of them are from first and second-tier cities with high per capita income and strong purchasing power. [27] Besides, some consumers are also increasingly looking for goods with independence and individuality (many companies allowing personalization of standardized goods, i.e. hi-tech.) [27].

2.3.4.2 Dutch consumers

The median age of Dutch consumers is of 42.6 years [29]. They are relatively affluent, but will not easily spend money. Since the world economic crisis, Dutch consumers remain cautious and are very sensitive to prices and special offers. [29] Quality is also an important concern. They tend to pay a higher price for a high-quality product. The trend is towards practical, healthy, and sustainable products. [29] Besides, the Dutch tend to resist change, which translates into the preference for their familiar products rather than new products.

2.3.5 Conclusion

This chapter has analyzed the current smart product market of China and the Netherlands, and the characteristics of the target consumers. Resulting in the following conclusion:

In the Chinese market, lots of highly cost-effective products appear, and consumers are willing to pay for them. However, not all the products are standardized, and the characteristics of these products are not evident. Since the price and functions are no longer the only factors that influence purchasing behavior, the target Chinese consumers are more willing to pay for goods with independence and individuality, which can also be described as the pride of identity.

In the Dutch market, the technologies are advanced, and the consumers are wealthy. However, cautious consumers do not show interest in smart products. They tend to pay for their familiar products which are more practical, healthy, and sustainable.

Different opportunities were found in these two markets. For the Chinese market, finding the differences and show the specialties are important. For the Dutch market, it is better to arouse people's interested in the product and make them realize they can use this cost-effective product to satisfy their basic needs.

Table 1. SWOT analysis on the Chinese market

	Strengths	Weaknesses
	1. A Huge market potential and development space. 2. Local companies produce various attractive products with reasonable price. 3. Consumers are interested in the new product and willing to pay for it.	1. Lack of standardization. 2. The core technologies need to be improved.
Opportunities	**SO**	**WO**
1. A rapid pace of life increase the need of smart floor cleaner. 2. The government and capital support for the development of new technology.	1. Keep develop in this market. 2. Developing new product with attractive functions or forms.	1. Establish a standard for the quality, the effect, etc. 2. Make the consumers feel their life qualities can be increased by this product (e.g. building a sense of achievement, healthy, etc).
Threats	**ST**	**WT**
1. The security problems (personal information leak, etc.). 2. Too many competitors for the same type of product.	1. Find the differences and show the specialties.	1. Find the user needs and design specific product for them.

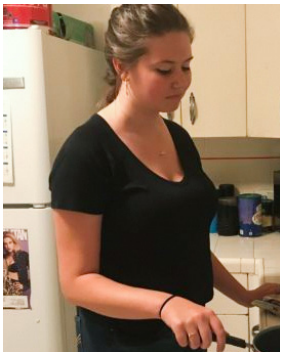
Table 2. SWOT analysis on the Dutch market

	Strengths	Weaknesses
	1. Have the high and new technologies in the whole required aspect. 2. A good cooperation between companies in different fields.	1. People do not show a great interest. 2. High price of the smart product.
Opportunities	**SO**	**WO**
1. Small number of competitors in local market 2. Consumers are interested in some smart products (e.g. lighting, energy, security, etc.).	1. A huge market potential to discover. 2. Developing products with specific functions (using adept technologies).	1. Entering the market with an affordable price. 2. Combining or adapting with existing popular products.
Threats	**ST**	**WT**
1. The international competitors	1. Adapting with their well-developed technologies on some special expertise areas. 2. Cooperating with international companies.	1. Starting from the point that people are interested in, such as being healthier, saving money, saving energy or increasing security, to arise their interest.

2.4 SYNTHESIS OF THE FINDINGS

2.4.1 Personas & storyboards

Personas and storyboards were created to represent the main problems and required functions of the analysis, in order to have a clear understanding of the current situations and problems. Two personas were created based on the results of the previous researches. Storyboards (Figure 23) were used to visualized the problems. It is worth noting that their characteristics (e.g. expectations, attitudes towards the smart products, etc.) were differentiated based on the cultural differences.



Anika (Dutch)

She will move away after half a year, so she doesn't want to buy useless things. But she wants to make sure everywhere is cleaned and to keep the room totally tidy when she was still here.

A typical day

7:30	Get up
7:30-8:00	Take a shower, comb hair.
8:30	Go to school
18:30	Back home
20:00-20:10	Wash face, brush teeth, go to the toilet...
23:00	Go to bed

About

Age: 23
Type of bathroom: share with other 2 girls (normal friends)
Job: Master student.
Attitude towards smart products: she is willing to try some cheap product but doesn't want to spend a lot of money.

Bathroom usage and cleaning habits:

They all attach importance to hygiene and prepare a detailed cleaning schedule to keep the bathroom clean.
She uses mop and duster cloth to clean the bathroom floor thoroughly during scheduled cleaning. Sometimes she will touch dirt when mopping the floor by hand, which makes her feel unpleasant.
There is a narrow gap between the wall and the washing machine. It always takes a lot of time and effort for her to clean.

Goals
Clean all the places and all the contaminants.
Spend less time and effort on cleaning.
Do not want to have too much fitments in the flat.

Dlighters
- The product is not expensive.

Needs
- Reliable cleaner. A product that can easily clean the narrow places.
- To make sure if the cleaning is good enough.

Frustration
- Buy the products that later found useless.

Bo (Chinese)

Bo is a busy designer. He doesn't like spending time on housework, especially cleaning the bathroom, but wants the bathroom to keep clean. Because of his job, he likes to buy and review new and interesting smart products.

About

Age: 26

Type of bathroom: use alone

Job: Designer. Busy work and high salary. But the living cost is also high.

Attitude towards smart products: Interested in a smart product and would like to try new things.

A typical day

7:30 Get up

7:40-8:00 Wash face, brush teeth, comb hair...

8:20 Go out to work

21:00 Back home

22:00-22:30 Take a shower

23:30 Go to the toilet, then go to bed

Bathroom usage and cleaning habit

All the shareholders are busy. They do not have a cleaning He is very busy and does not have a cleaning schedule. He only cleans the bathroom when it looks dirty. He has domestic service every two weeks.

He doesn't like doing housework, especially cleaning the bathroom. He does not want to close to dirt and throw away the dirt after cleaning.

He often has to work overtime, so he goes home very late. Sometimes when he wanted to take a shower but found some hair and sewage on the bathroom floor. He had to clean the bathroom and then take a shower, which makes him annoyed.

Goals

Find a smart cleaner to replace the domestic service. Since the domestic service becomes more and more expensive, he decided to clean the room himself. However, he hates to do housework, especially to clean the bathroom. So he wants to find a new product that can clean the bathroom automatically.

Dlighters

- Try the new and advanced product.

Needs:

- Easier cleaning. Automatic cleaner to clean the whole bathroom every week.
- Not touch the dirt.

Frustration

- The product is hard to operate and takes time to be taken care of.

Main expectations

The main expectations of Anike and Bo are summarized in figure 22. Their emotional expectation can be concluded as a sense of trust and effortless.

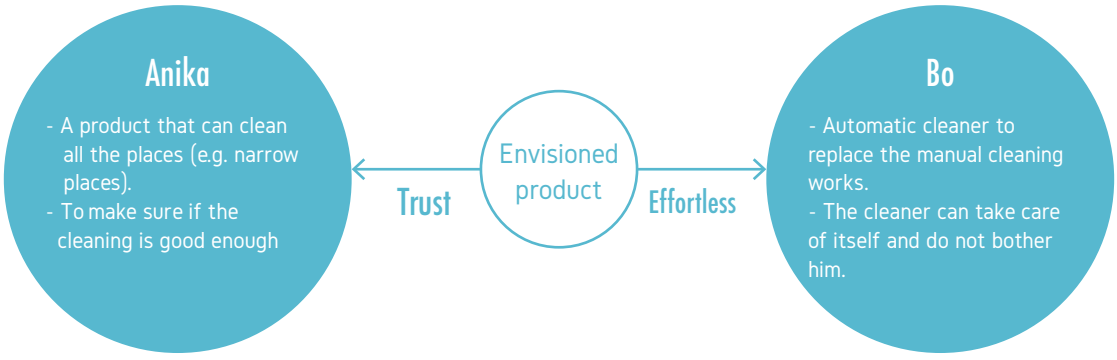
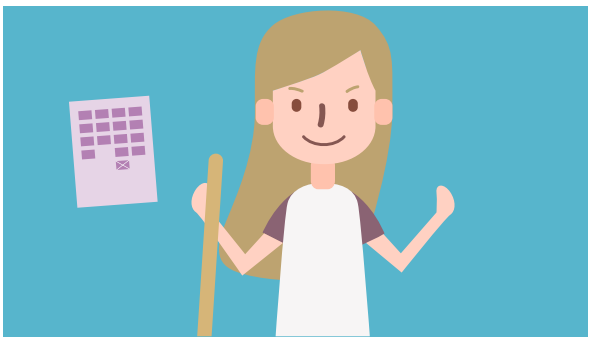


Figure 22. Main expectations

Storyboard 1: Scheduled and global cleaning



1. It was Anika's turn to do the house clean this Sunday

2. The narrow space between the washing machine and the wall is hard to reach by the mop.

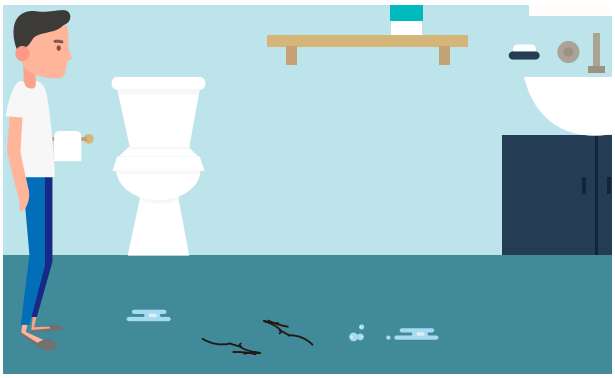
3. She had to use hand to clean, which took her lots of time.

4. After cleaning, all the other places looked good. However, she was worried that the corner had not been cleaned.

Figure 23-1. Storyboard scheduled and global cleaning

Storyboard 2: Incidental and local cleaning

1. After a whole day's work, Bo arrived home at 9 pm.



2. When he went to take a shower at 11 pm, he found the bathroom floor hadn't been cleaned for a long time.

3. Although very tired, he didn't want to take a shower in a dirty bathroom. So he quickly cleaned the floor.

4. After cleaning, he didn't want to touch dirt, thus did not know how to deal with it.

Figure 23-2. Incidental and local cleaning

2.5.2 Expectation description

The formulation of the conditions, expectations, and opportunities were classified by different groups in Figure 24. These clusters are used to find the core of the problems, which will be the start of the ideation and conceptualization phase.

All the clusters can be summarized into two aspects: the device-environment aspect and the device-human aspect.

The expectation related to the **device-environment aspect** is about how the device cleans the environment. The device is expected to fit with the special conditions of the bathroom context, to be multifunctional, and can adapt to different working spaces and situations (such as to clean different kinds of contaminants, to move across narrow places, to clean itself, etc). Although the users want this product to be a powerful cleaner, they do not want their daily bathrooms uses to be bothered. They expect the product to manage the bathroom cleaning as well as itself automatically, and only give feedback when the users need it.

For the **device-human aspect**, the expectation n be further developed to the emotional level of demand. Specifically, since even being cleaned by others does not mean the floor is clean, the user should trust the cleaning ability of the device. The expectation of saving time and effort, as well as wanting a convenient and lightweight product, can be summarized as want to be effortless.

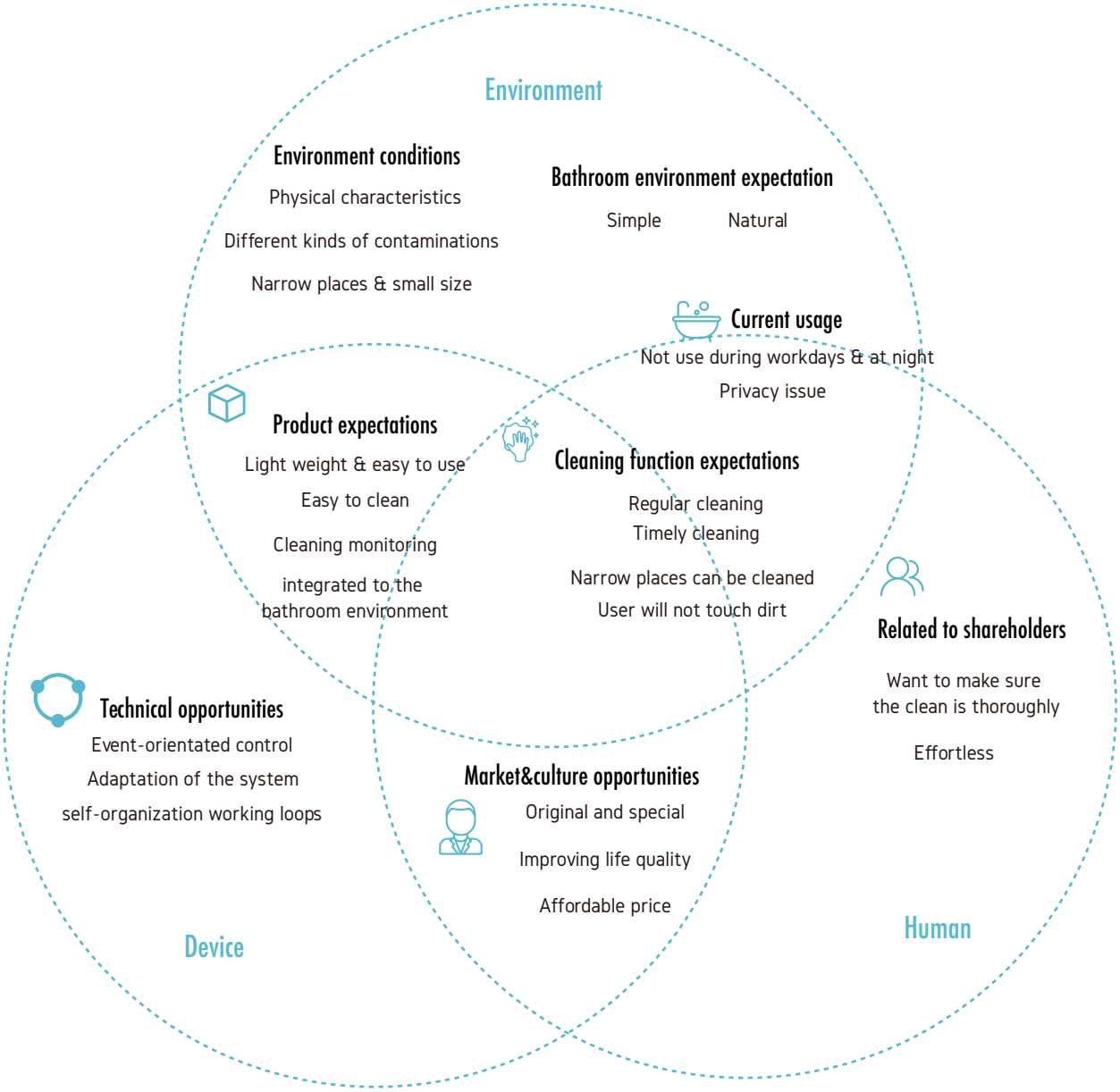


Figure 24. Overview of the conditions, expectation, and opportunities

2.5.3 Design Goal

As discussed in the 2.5.2 - expectation description, the expectations lay in two aspects. To sum up, the design goal is to let the Chinese and Dutch young adults who share a bathroom with others harmoniously manage their bathroom floor cleaning tasks.

The design goal will be reached in two aspects:

A. Device-environment aspect

The main function of the envisioned product is to help the users clean their bathroom floor. Considering the specific situations in this project, the product should:

a. fit with the bathroom environment.

b. sweep or deeply mop the whole bathroom floor incidental or thoroughly.

c. handle the contaminants after cleaning.

B. Device-human aspect

The previous analysis found that the product should achieve the emotional expectations of users. Specifically speaking, this product should:

a. take care of the bathroom floor cleaning and itself automatically. Although some of the tasks may not be fully automated, the time and effort that the user spends should be significantly reduced.

b. the cleaning that the device has done should be trusted by the user.

To sum up, the design goal was refined:

to offer an effortless and trustful experience when cleaning the bathroom floor.

In this way, the design will be able to improve the bathroom floor cleaning experience for the young adults who share accommodation, and finally to offer an efficient life.

2.6 DESIGN REQUIREMENTS

2.6.1 Approach of stating requirements

The requirements were obtained from the findings of the previous aspects and grouped by environment aspect, human-related and technology-related.

Context aspect: environment related requirements, user group requirements, emotional expectation requirements.
Technology aspect: cleaning task requirements, function requirements, cyber-physical system requirements.
Market aspect: smart product expectation requirements, price requirement.

Environment related: environment related requirements,
Human related: user group requirements, emotional expectation requirements, price requirement.
Technology related: cleaning task requirements, function requirements, cyber-physical system requirements.

2.6.2 Requirements list

Environment-related

- The operation of the product needs no illumination.
- After cleaning, no surface gathered water would be left.
- The main part is waterproof and the cleaning part of the product is skid resistance.
- The diameter of the cleaning part should be smaller than 100 mm in order to reach the narrow places.
- The cleaning part of the product can clean the corners.
- The product does not use a camera in the bathroom.
- The product does not disclose personal information.
- No special skills required to operate the product.

Human related

User group requirements:

- The target users of the product are defined as Chinese and Dutch young adults:
- University students or new employees.
- Clean the bathroom in person.
- Have the ability to buy smart home products.

Emotional expectation requirements
related to bathroom usage and cleaning expectation:

- trust, the product should gain the user's trust in their ability of cleaning; (value)
- effortless, the operation of the product should be simple and direct, and do not take much time and effort.

Technology-related

Function requirements:

Cleaning functions

- The product can distinguish the type of contaminants based on cleaning methods.
- The product can clean solid contaminants (hair, dust, etc.).
- The product can clean damp contaminants (puddles, water stain, and foam).
- The product can clean mixed contaminants (soap scum, wet hair, mold, and furring).
- The product will not cause secondary pollution.

Driving functions

- The product can mapping the bathroom layout by moving along the edge of the wall and object.
- The product can plan the path.
- The product can avoid fitments on the floor.
- The movement will be kept in the bathroom.

Charging

- The power supply of the cleaning part is wireless.
- The product can monitor the usage of the power of each part.
- The cleaning part can go back to charge if the power is not sufficient.

Self-cleaning

- The dirt on/in the product can be easily cleaned.

Proper cleaning

- The cleaning area can be monitored.
- The cleaning histories are reachable.

Other functions

- The product can sense the presence of a human in its working spaces.
- The product can respond to the emergency.

Cyber-physical system requirements

- The product consists of physical and cyber components.
- Each part of the product can communicate with each other.
- The product can deal with different events.
- The functional parts can work together or individually based on the event.

3. CONCEPTUALIZATION

3.1 INTRODUCTION

The conceptualization phase focuses on using the results of the analysis phase to realize the proposal set at the beginning of the project. To be specific, the aim is to put forward interaction concepts between the user, the smart bathroom floor cleaner, and the bathroom environmen. However, the smart bathroom floor cleaner is still missing. Therefore, this phase consists of two parts: 1) a device concept of the smart bathroom floor cleaner which contains its appearance and the main functions of it, 2) several interaction concepts for finding the promising interactions of using this smart device. Cyber-physical system principles are used in this phase to generate a smart device concept and to inspire the interaction concepts.

3.2 APPROACH

In this design, three major elements need to be taken into consideration: device, environment, and human. The conceptualization phase is divided into two parts: 1) how the device works in the environment and 2) how the users interact with the device and the environment.

Since a workable device is the fundament for designing the interactions, the first stage of the conceptualization is to develop a smart cleaner device concept (Figure 25). In this stage, the device - environment interaction was discussed, which is to reach the function and environment-related requirements. From these requirements we got the necessary functions for the device. Then, these functions were divided into physical functions and cognitive functions, which are distinguished by the technologies they use (details in 2.2.4.1-CPSs implementation technologies). The function groups were discussed one by one and eventually form an integrated device concept. A detailed approach to developing the device can be found in the 3.3.2 - Device concept approach.

The researches related to the context and martket (details in 2.1.4-Context aspect conclusion and 2.3.5-Market aspect conclusion) show that the Chinese and Dutch users have different attitudes towards smart products. Besides, the discussion of this project is in also in the context of CPSs. Therefore, the intelligence level of CPSs from the technology requirements (details in 2.2.4.3 - Levels of intelligence) becomes the starting point of designing interaction concepts. After coming up with a relatively complete device concept, the workflows of the device, the bathroom environment, and the users, of the main scenarios were drawn, to find the touchpoint of human - device interactions. Three concepts with different intelligence and contains the interaction functions were then created. The main emotional expectation requirements that trustworthy and effortless are used for the later evaluation. A detailed approach to developing the interaction concepts can be found in 3.4.2-Interaction concepts approach.

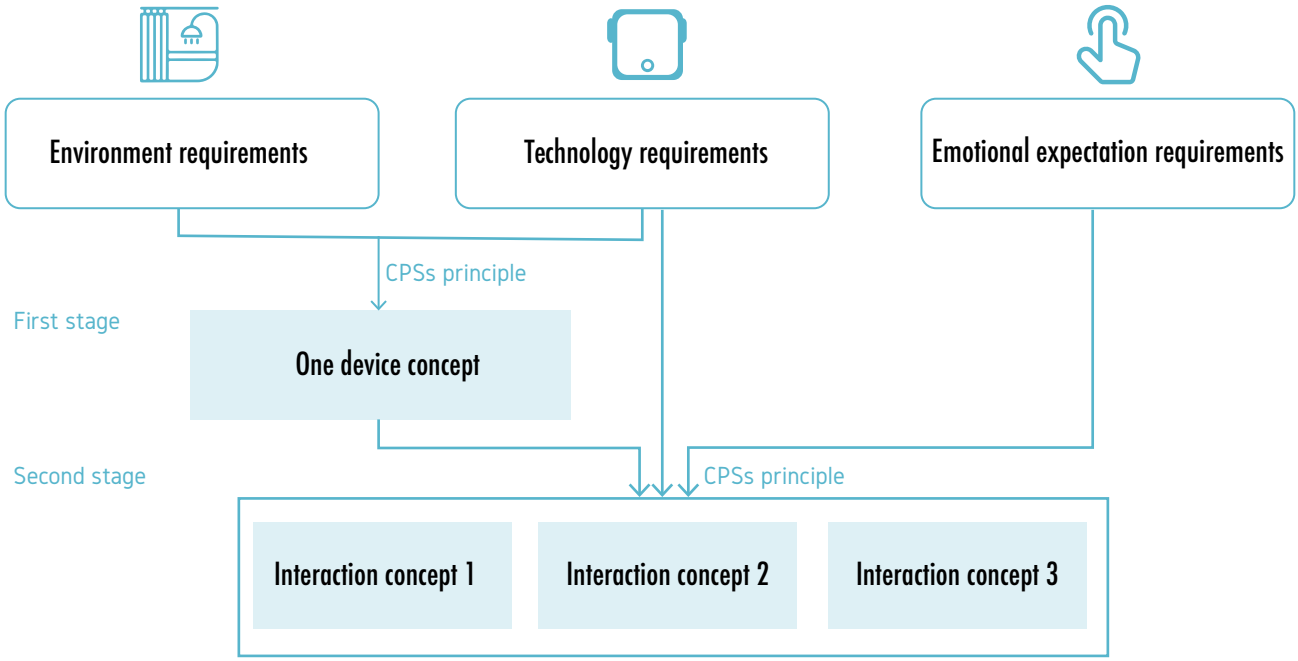


Figure 25. Conceptualization phase approach

3.3 DEVICE CONCEPT

3.3.1 Introduction

The aim of this part is to develop an integrated device concept that can reach the environment and technique requirements.

3.3.2 Approach

From the requirements in 2.6.2, we found that the composition of the device is complicated. Since CPS is an event-orientated system (2.2.4.2 - Principle of event-orientated control), the discussion of each part will be based on different functions that indicate different events. Therefore, we can separete the whole device into smaller parts based on the cleaning events they are related. Then, design these parts step by step.

In a cyber-physical system, every system is regarded as a structure of cyber components and physical components, and a synergic system that couples the pure cyber and physical system. [17] (2.2.4.1- CPSs implementation technologies) Each component has its related technologies (Figure 21 in 2.2.5-technology aspect conclusion). Because the product has the characteristics of CPSs, we can separate the functional parts by the related technologies into physical components that used the physical technologies and cognitive components that used synergic and cyber technologies.
The following are the specific functions (also illustrated in Figure 26).

A. The physical functions
The physical component contains the functions/ requirements that used physical technologies such as material technologies or robotic technologies. This part contains the following functions:
a) reaching the narrow places and corners,
b) cleaning different contaminants,
c) Self-cleaning.

B. The cognitive functions
The part contains all the other functions that use cyber or synergic technologies, such as sensor technologies, communication technologies. The functions in this part are:
1) starting a cleaning task
2) dirt detection during cleaning
3) human presence response
4) emergency response
5) self-cleaning system monitor
6) self-charging

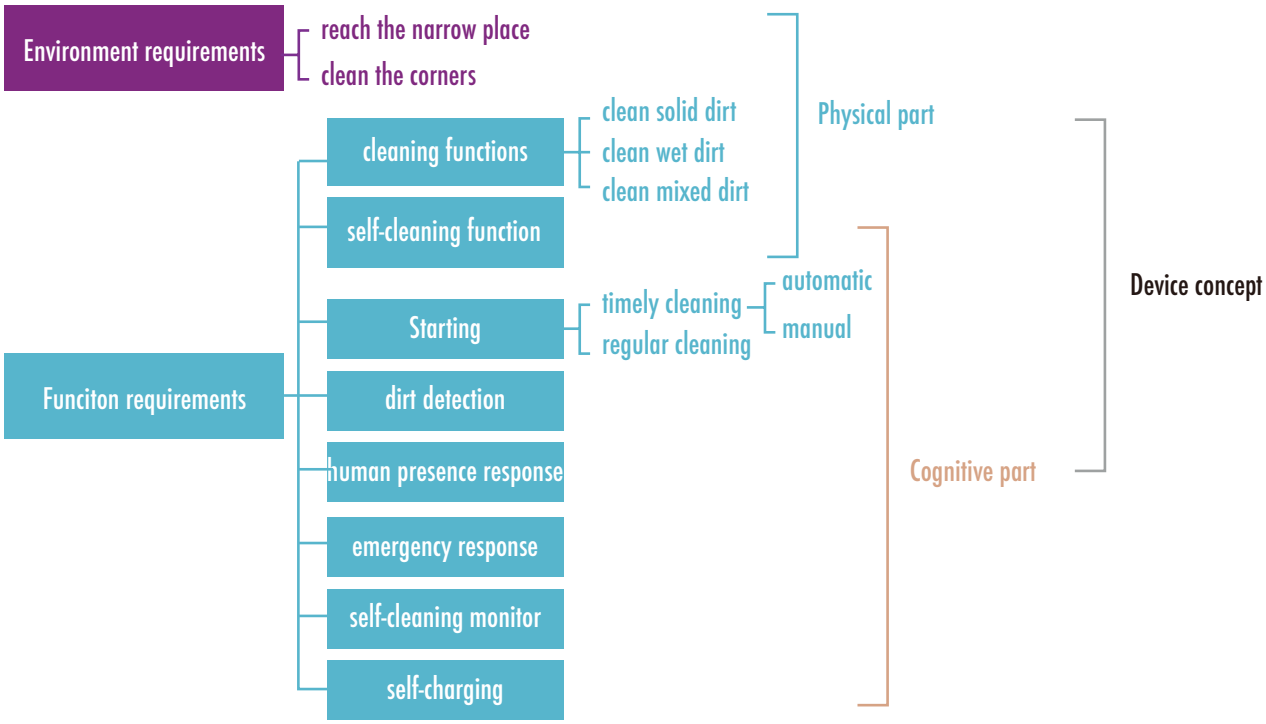


Figure 26. Functions of the device concept (based on the requirements)

3.3.3 Physical part development

3.3.3.1 Three previous ideas

Goal :
The aim of this part is to efficiently generate ideas for the related functions of the physical part and integrated these functional modules into physical device ideas.

Method :
As a brainstorming method, how-tos were used to create several solutions that could be combined to create the device functions. The how-to questions were developed from the subgoals of the design goal, and are associated with the physical related functions. The specific questions are:
1. How to clean different places? (normal places and narrow places)
2. How to clean different contaminants? (e.g. dry, damp, and stubborn dirt)
3. How to clean itself?

Procedure :
In the beginning, the topic of the project and the main findings of the context, technology, and market aspects were introduced. Then, the design goal and requirements were told. After a short explanation about the brain drawing process, the papers with one 'how-to' question were distributed to the participants. Then, they were given five minutes to draw three ideas for the questions on the paper, and then passed this paper to the next participant and received a new one.

Results :
After the session, many ideas for each function were created. Then, similar ideas were classified into the directions in Table 3. Then, these physical related ideas are combined into the following concepts.

Table 3. Physical related ideas

1. Clean different places (normal / narrow places)	2. Clean different contaminants	3. Self-cleaning
A. Small piece The size of the central part is large to efficiently clean the normal place, while part of the device (e.g. a robotic arm) is small and flexible to reach the narrow area.	A. Different cleaning tools There is a specific cleaning tool for each type of dirt. For instance, sweep to clean dry dirt and mop to clean wet dirt.	A. Disposable modules The cleaning modules are disposable. The used module can be throw away and a unused module can be equipped automatically.
B. Deformable shape The shape can deform to fit different situations. For instance, the cleaning part can expand to clean the normal place and narrow down to clean the corners.	B. The same tool with several using methods Using one tool to clean different specks of dirt, but the operating methods of the tool are different.	B. Inner cleaning systems Using inner cleaning systems to clean the used modules.
C. Small size Each part of the cleaning part is small to reach the narrow place, while they can also work together to increase the work efficiency.		

1A 2A 3A

Concept 1: Traditional cleaner

The form of the first concept is adapted from the traditional mopping robot in the current market. A robotic arm on the top of the device is used to clean narrow places. Different cleaning pads were equipped to clean different dirt. After cleaning, the used pads and the dirt on the pads will be gathered into an inner trash can.

Figure 27. Device concept traditional cleaner

1B 2B 3A

Concept 2. Transformer

The form of this concept is based on the idea of the deformable shape. When the cleaning pad moves from different directions, the size of the space it can enter and the cleaning efficiency will vary. Same cleaning pads will be used. Since the cleaning tool is also a mopping pad, the dirt will also be gathered into an inner trash can after cleaning.

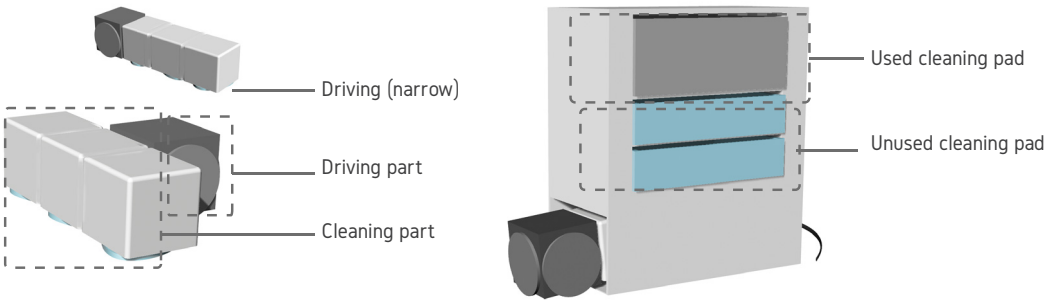


Figure 28. Device concept transformer

1C 2A 3B

Concept 3. The cubes

The basic form is small size cleaning cubes that can move into the narrow places. The cubes can equip different cleaning tools to clean different specks of dirt. The handling dirt method is adapted from the previous technology research, which is using an inner vacuum and washing system to gather dirt.

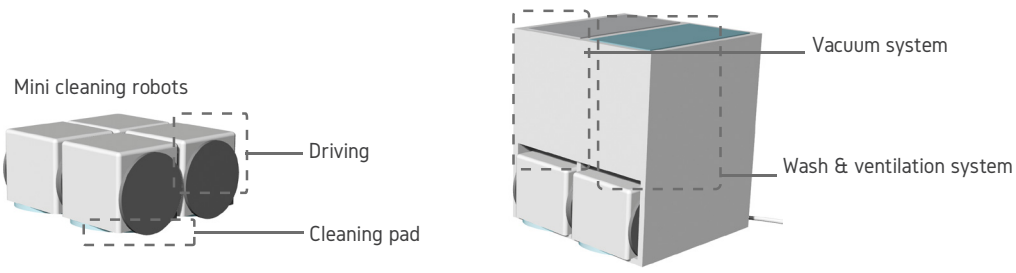


Figure 29. Device concept the cubes

3.3.3.2 Physical part evaluation

Goal

Collect target users' evaluation of the three selected concepts. Then select the most promising concept which could offer users an effortless, trustworthy and proud cleaning experience.

Setup

The selected concepts were visually represented by 3D-CAD models. In order to make the participants better understand the details and the operating principles, we showed pictures of real products which has similar functions next to the 3D-CAD models (figure 30). Besides, we prepared a preference questionnaire for the participants. The questions include what are their preferred ways of solving each 'how-to' problems and what is their favorite integrated concept.

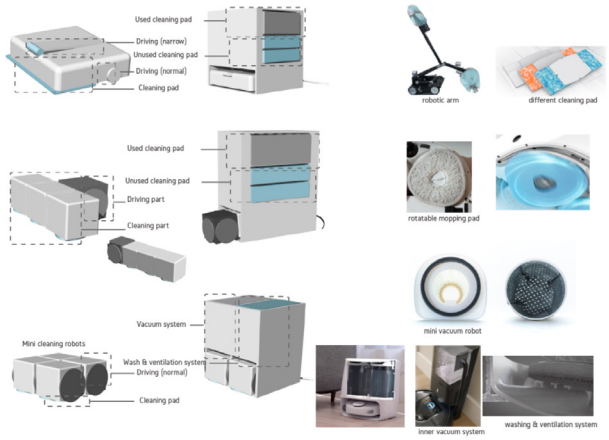


Figure 30. Stimuli for physical part evaluation

Figure 31. A participant is filling the questionnaire

Participants

5 Chinese and 5 Dutch young adults.

Procedure

After introducing the topic of the project, we explained the three physical functions of each concept based on figure 30. Then, the participants need to fill in the preference questionnaire and explain the reasons. During the introduction and questionnaire filling, the participants were free to ask questions and give comments. One of the evaluation is shown in Figure 31.

Results

For the reason of making a choice, the result is shown in figure 32. Although the number of participants is not enough to get quantitative conclusion, the chart shows a rough preference that all functions and the overall device of concept 3 are the most preferred concept.

For the reason of behind, we summarized the participants' comments on each concepts and their explanations after completing the questionnaire. The results are as follows:

- Cleaning different contaminants

The participants said that using different cleaning pads or different cleaning robots seemed more professional and the result might be more reliable.

- Clean different places

The small size looks flexible but should be easy to control. Most participants mentioned that the small cube cleaners looked easier to start working, and more flexible to reach the narrow places. Some participants were worried about whether the small robots were controllable since there were too many (four parts) in the poster.

- Self-cleaning

The sustainable self-cleaning way is preferred, but may not the best solution. Comparing with disposable cleaning pads, most of the participants were willing to use a sustainable cleaner, even if they need to put more effort into taking care of it. The main reasons include 1) to perform environmentally friendly and 2) to save money. Participants mentioned that using disposable pads cannot save time since buying new pads also need efforts. Although many users chose the sustainable device and accept to change water manually, some of them still hoped the process can be automatic.

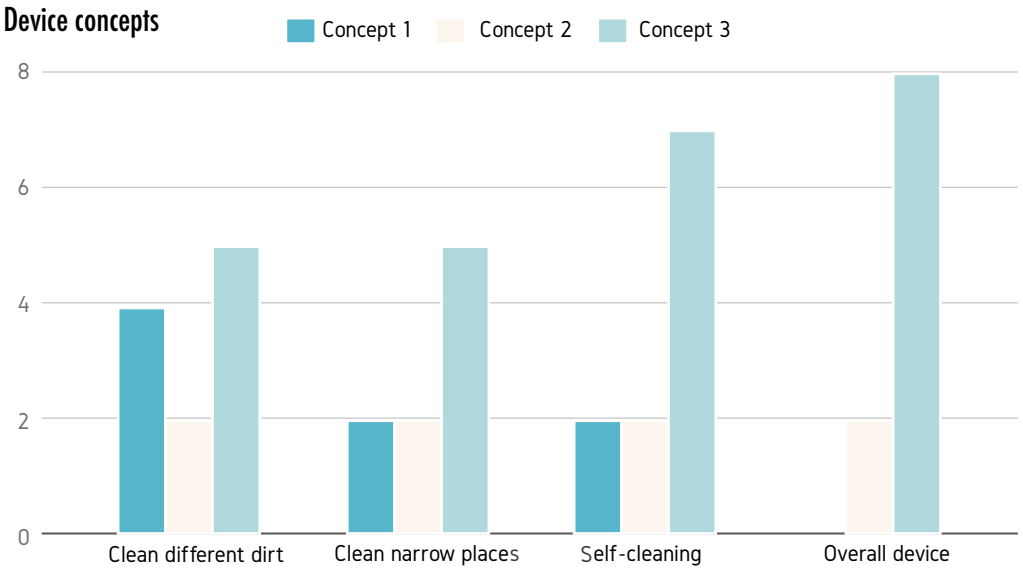


Figure 32. Device concept preference

Conclusion

Based on the results above, we can conclude that the Concept 3-the cubes is the most promising concept for future development. The physical part of the device (Figure 33) is refined based on concept 3.

The functions of cleaning different contaminants will be achieved by using specific cleaning methods, to be specific, a vacuum robot to clean dry contaminants like hair, and a mopping robot to clean wet and stubborn contaminants like sewage.

For the function of cleaning different places, the number of mini-robots should be carefully decided. Considering environment requirements that the size of the bathroom is not large, we decide to use two basic cleaning robots: a vacuum robot and a mopping robot. In addition, reasoning from the general bathroom layout, we speculate that a robot with a side length of 10 cm will be able to enter most of the narrow areas of the bathroom.

For self-cleaning, we decide to use the inner self-cleaning system, which includes a vacuum system and a washing & ventilation system. This self-cleaning process is not fully automated, users need to manually throw the garbage bag and change the water. But the results show that they can accept this level of manual operation.

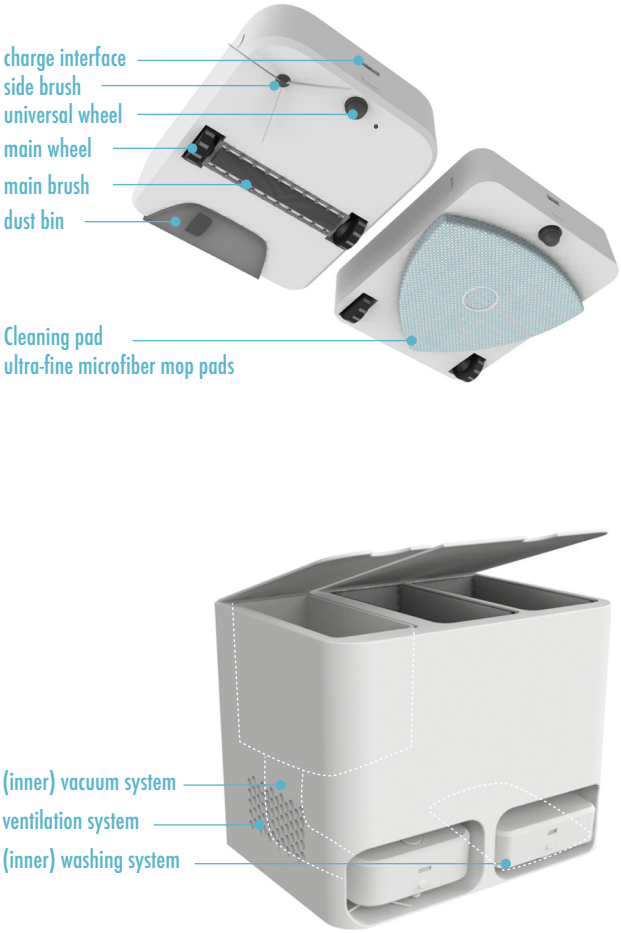


Figure 33. Early device concept

3.3.3.3 Expert evaluation

Goal

Due to the limitation of knowledge level, there are still some imperfections in the early device concept that should be solved. Therefore, we had an evaluation session with experts to find those problem and the possible solutions.

Procedure

We introduced the desired functions and explained the current structure of the physical part of the device concept. Then, the expert pointed out the following questions:

Q1 Is the product able to reach narrow places and corners?

Q2 How to do the inner self-cleaning?

The early idea of the product used a rectangular body with a side brush to reach the corner, which is a traditional solution for the products in the current market, such as Roomba (iRobot, 2002) and Roborock (Xiaomi, 2017). However, depending on the actual cleaning experience, this solution does not clean the corner well. Therefore, it is a problem needs to be solved.

Although the participants in the previous evaluation considered the inner self-cleaning system to be the best solution for self-cleaning, we did not design the internal structure of the system. Therefore, it is necessary to consult a feasible internal structure scheme.

Afterdiscussing with the experts and redesigning the related physical parts, we got the following solutions.

Results

R1 For cleaning the corners

The shape of the cleaning pad can be designed in a rouleaux triangle (Figure 34). This shape can perform a complete rotation while staying within the square and at all times touching all four sides of the square [34]. When the robot feels the wall, it will turn to a fixed angle to clean the dust in the corner

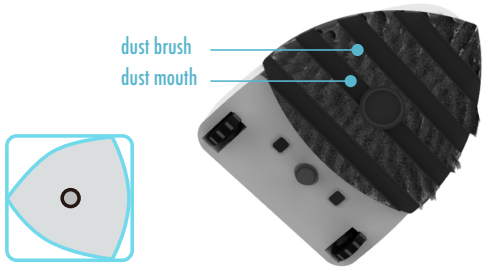


Figure 34. The shape of rouleaux triangle

R2 For the structure of self-cleaning system

Overall: The self-cleaning system is formed by a inner box changing system and a wash & ventilation system (Figure 35).

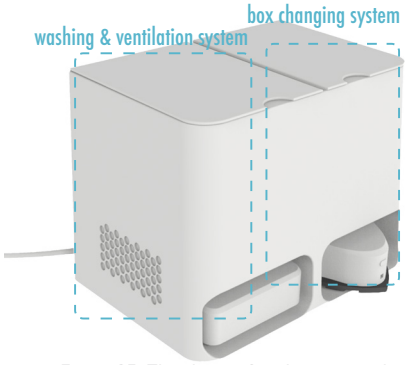


Figure 35. The shape of rouleaux triangle

R2-1 An inner box changing system for the vacuum cleaner: The electromagnet ladders in the base station and the magnets on the dust boxes form a dust box changing system (Figure 36). In this system, the dirty dust box will be removed from the vacuum robot and a clean box will be equipped later. The specific steps of box changing are shown in Figure 37.

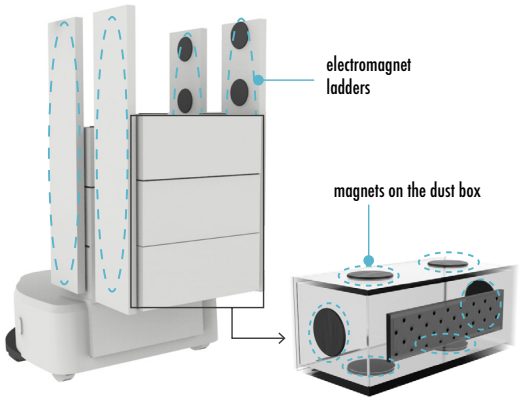


Figure 36. The shape of rouleaux triangle

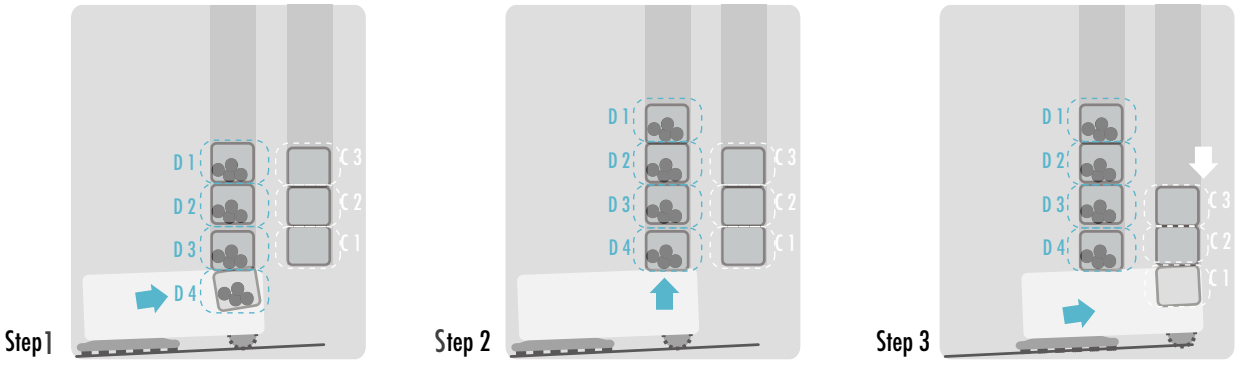


Figure 37. The steps of changing dust box

Step 1: After a cleaning task, the vacuum robot (with dirty box D4) moves into the base station.

Step 2: The vacuum robot ejects the dirty box D4, then the box D3 attracts the box D4. The electromagnet ladders cancel magnetic and send the dirty boxes on at the same time. After the dirty boxes meet their next electromagnet point, the ladders will attract them again.

Step 3: The vacuum robot moves further inside and stops below the clean boxes. The electromagnet ladders of the clean boxes cancel the magnetic and the clean boxes dropdown. The magnet on the vacuum robot will attract and then equipped with the clean box C1.

R2-2 An inner wash&ventilation system for the mopping cleaner (Figure 38):
After a mopping task, the mopping robot moves back to the base station. The mopping pad rotates in the cleaning pool to clean itself with the water from the clean water tank. Then, the dirty water will be pumped into the dirty water tank. At last, the ventilation fan will ventilate the cleaning pool to keep it dry.

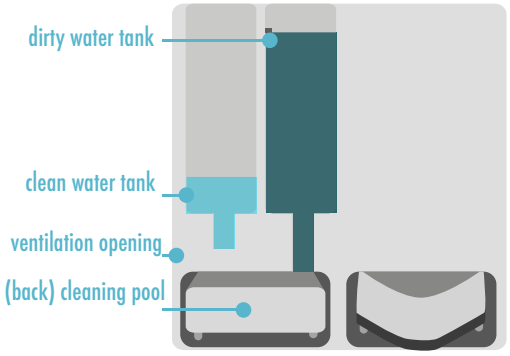


Figure 38. Washing & ventilation system

3.3.4 Cognitive part development

In this part, we analyzed the main cognitive parts which apply cyber technologies and synergic technologies. We summarized the cognitive functions from the design requirements and will discuss the data flow and sensor arrangements according to the functions.

The cognitive functions are:
1) starting a cleaning task
2) dirt detection during cleaning
3) human presence response
4) emergency response
5) self-cleaning system monitor
6) self-charging

3.3.4.1 Start a cleaning task

The previous research shows that there are two cleaning modes. One is incidental and quick cleaning tasks that only clean the contaminated place, which can A) Incidental start. The other is thorough cleaning tasks that clean the entire bathroom floor, which icontains B) Manually start C) start on schedule.

A. Incidental starting

The incidental starting consist of two stages. Figure 39 shows the relationship between the length of use and cleaning accuracy. Briefly speaking, the device needs to continuously learn the data from the environment, the users, and the cleaning tasks in the early stage. After gathering sufficient information, the device will start to reason more accurate starting time, cleaning type and contaminated places for the automatic cleaning tasks. How the device decides the cleaning type and recognizes the contaminated place will be introduced detailly in the 3.3.4.2-Dirt detecting and reasoning.

Figure 40 shows the data flow of incidental cleaning in stage 1. Due to the human presence sensor on the base station, the device is able to record the usage time point and duration of the user. Besides, the environment characters such as humidity and temperature at present are also recorded by the corresponding sensors. This information will be sent to the incidental cleaning task database and be created into cleaning events. Every time the user leaves the bathroom, the cleaning robots start cleaning the entire bathroom floor. During the cleaning, the contaminated place and the type of dirt will be recorded and paired with the previous cleaning event. The user will be notified when the cleaning starts and finishes.

After a period of data collecting, the device will gradually adapt to the bathroom contaminating pattern of the users, and make cleaning events more precise. Figure 41 shows how the device reasons incidental cleaning tasks. The ambient characters and the human's usage characters will be sensed and then sent to the incidental cleaning task database. If they match a cleaning event, the database will tell the reasoning type and place of the contaminants to the base station. Then, the specific cleaning robot will be sent out to clean the reasoning place rather than the entire floor. Also, the cleaning task information will be sent to the user and the database.

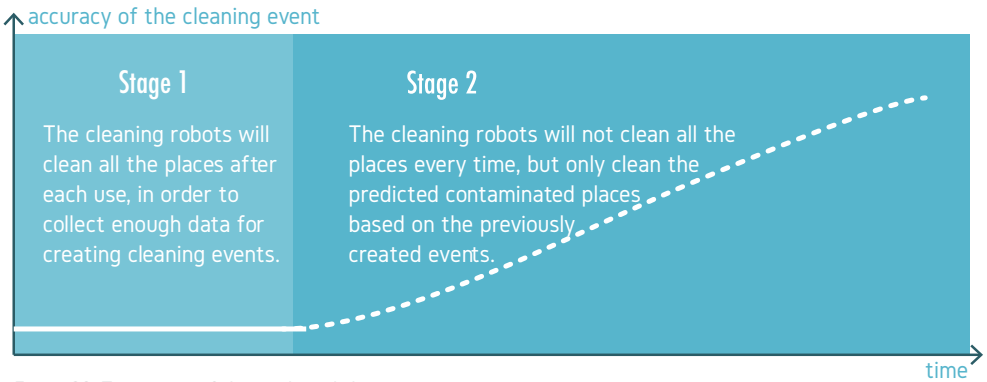


Figure 39. Two stages of the incidential cleaning

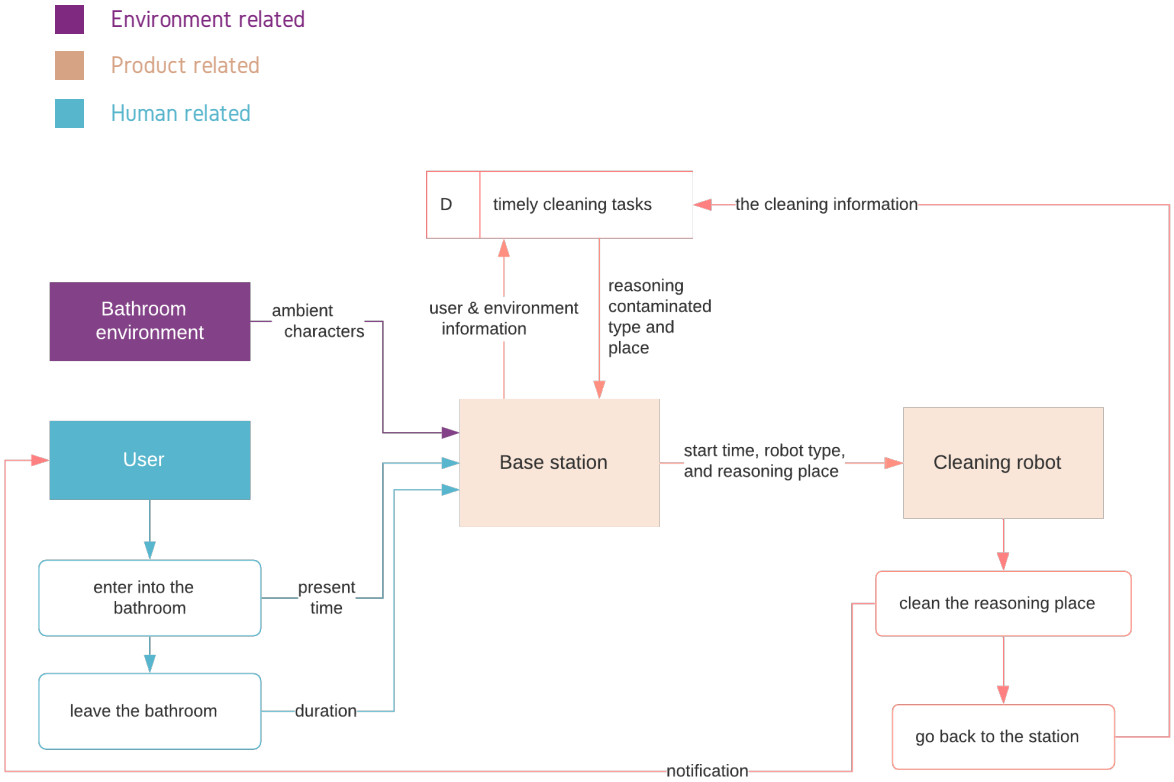


Figure 40. Incidental starting data flow (Stage 1)

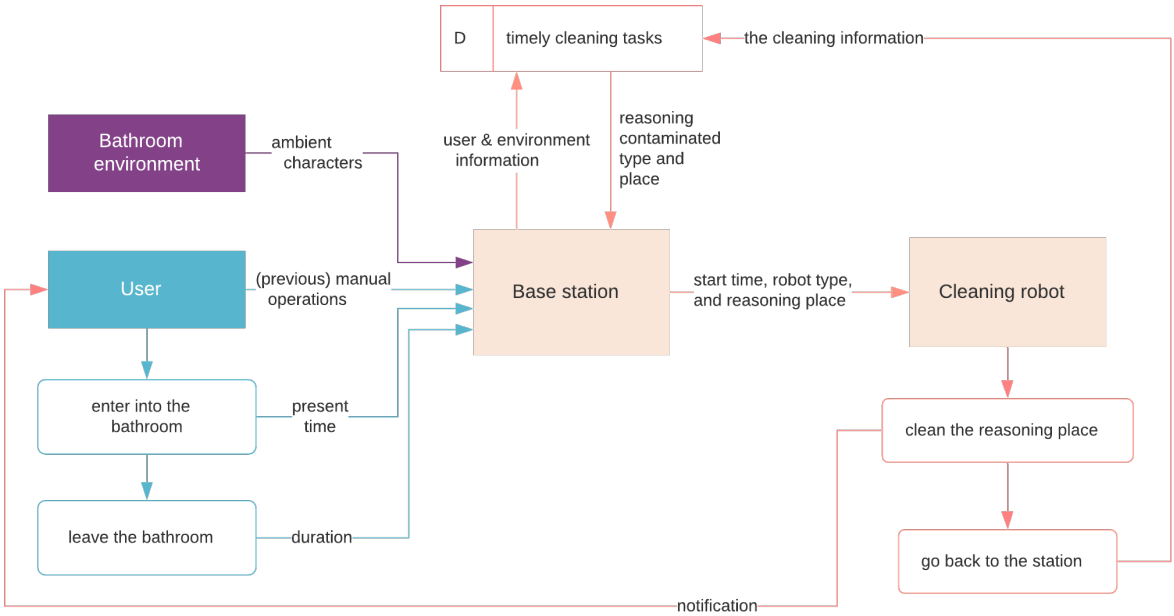


Figure 41. Incidental starting data flow (Stage 2)

B. Manual starting

Apart from the incidental starting, we can also start a cleaning task manually. After the user launches a cleaning task, the base station will immediately send out the appointed robot to clean the entire floor. The starting time, appointed robot, and the contaminated places will be sent to the incidental cleaning task database, to improve the incidental cleaning events. The user will receive a notification about the cleaning. The data flow is in Figure 42.

C. Scheduled starting

Setting scheduled cleaning (Figure 43) is the third way to start a cleaning task. The user can manually set a scheduled cleaning task which contains the cleaning time, robot type, and frequency. The settings will be stored in the cleaning schedule database. One day before a preset cleaning, the device will receive notification from the database to remind the user to remove the objects on the floor. At the set time, the two cleaning robots will follow the instruction to clean the entire bathroom floor. The cleaning information, such as the amount and type of dirt and the contaminated place, will be sent to the database. Same as other cleaning tasks, the user will receive a notification about this cleaning.

The related sensor includes human presence sensors on the base station, temperature and humidity sensors on the base station, and dirt detecting sensors which will be introduced in the 3.3.4.2-dirt detecting.

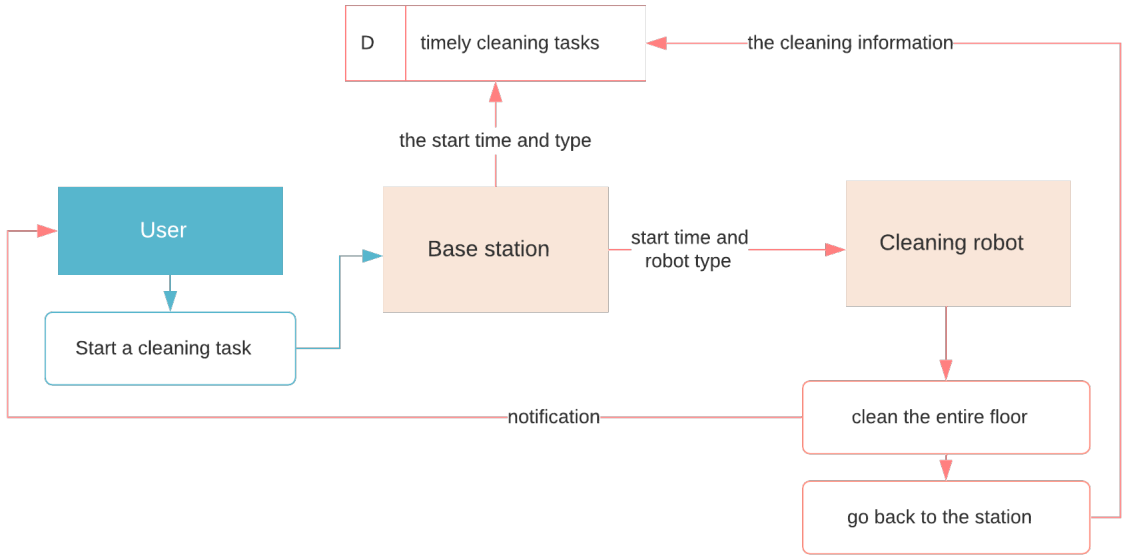


Figure 42. Manual starting data flow

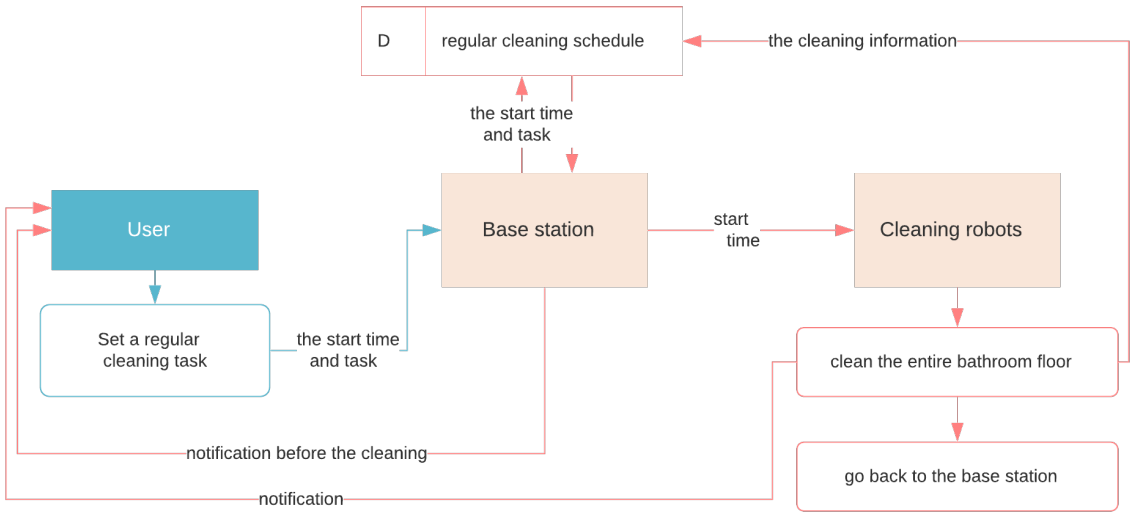


Figure 43. Scheduled starting data flow

3.3.4.2 Dirt detecting

The previous introduction mentioned that the device is able to reason the contaminated place of an automatic incidental cleaning, which means the device can detect the type and place of the contaminants. Figure 44 shows the data flow of this cognitive process. After a cleaning task starting (manually or automatically), a specific robot will be sent out to clean the floor. The sensors at the entrance of the dust box can sense the entering of the solid dirt. Together with the inner navigation system, the vacuum robot can detect where the solid dirt is. For the wet dirt, sensors on the wheels of the two cleaning robots are able to sense the wet place when they are moving. The information about the position of the solid and wet contaminants will be sent to the incidental cleaning tasks database for improving the accuracy of the cleaning events.

One thing that needs to point out is that in the stage 1 of the incidental cleaning, the vacuum cleaner will first clean the entire floor and sense the wet place. Then, it will send the information about the wet place to the mopping robot. In this way, the mopping robot can directly mop the wet place rather than mop the entire floor.

The sensor arrangements include infrared sensors and ultrasonic wave sensors in the dust box of the vacuum robot, the rain sensors on the wheels of the two cleaning robots (Figure 45).

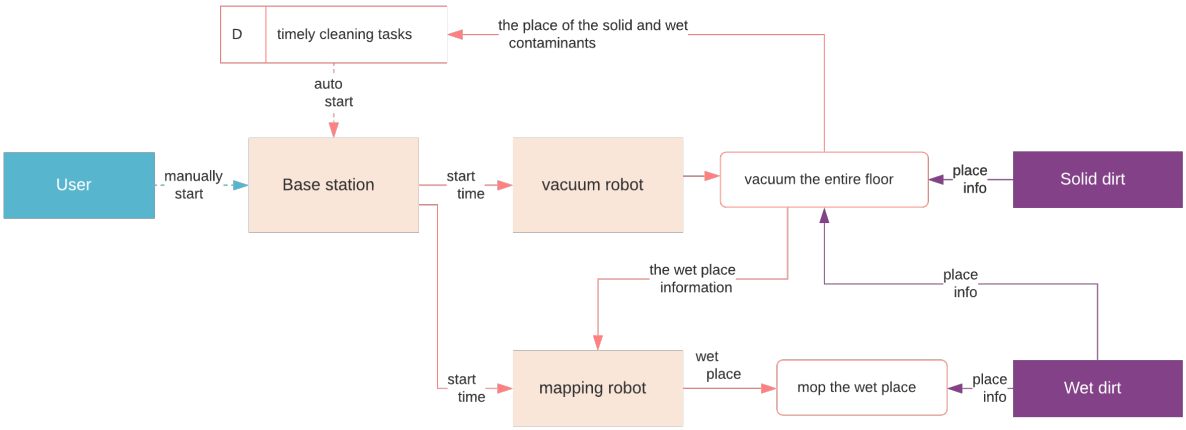


Figure 44. Dirt detecting data flow

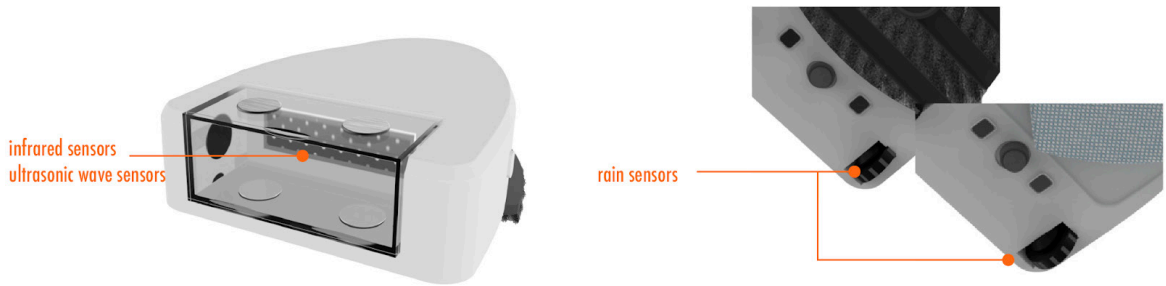


Figure 45. Dirt detecting related sensors

3.3.4.3 Human presence response

There are two situations relate to the situations that human presents in the bathroom. The first is the user launches a cleaning task in the bathroom. The second is the user interrupts a cleaning task.

For the first situation in Figure 46, if the user's presence and the manually starting command appear at the same time, the cleaning robot will follow the command to finish the cleaning task. In other words, the robot will start working when the human is in the bathroom in this situation.

For the second situation shows in figure 47, the working robot will pause the current task when the human interrupts. After the human leaves the bathroom, the cleaning task will automatically restart. The time point and duration of the human's presence will be recorded in the incidental cleaning tasks database to improve the starting time of the incidental cleaning.

The related sensor in this function is human presence sensor on the base station.

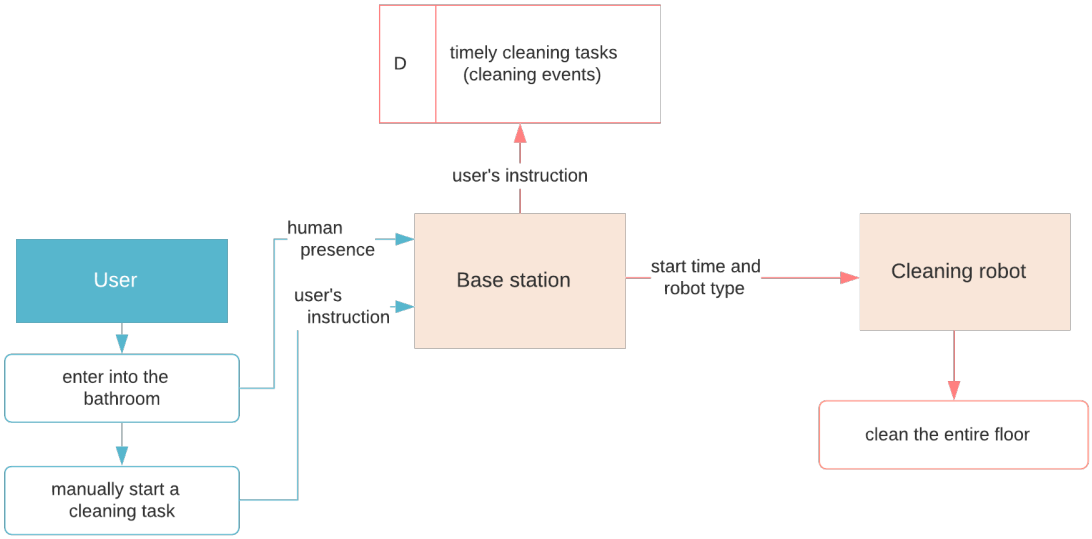


Figure 46. Human presence respond (situation 1)

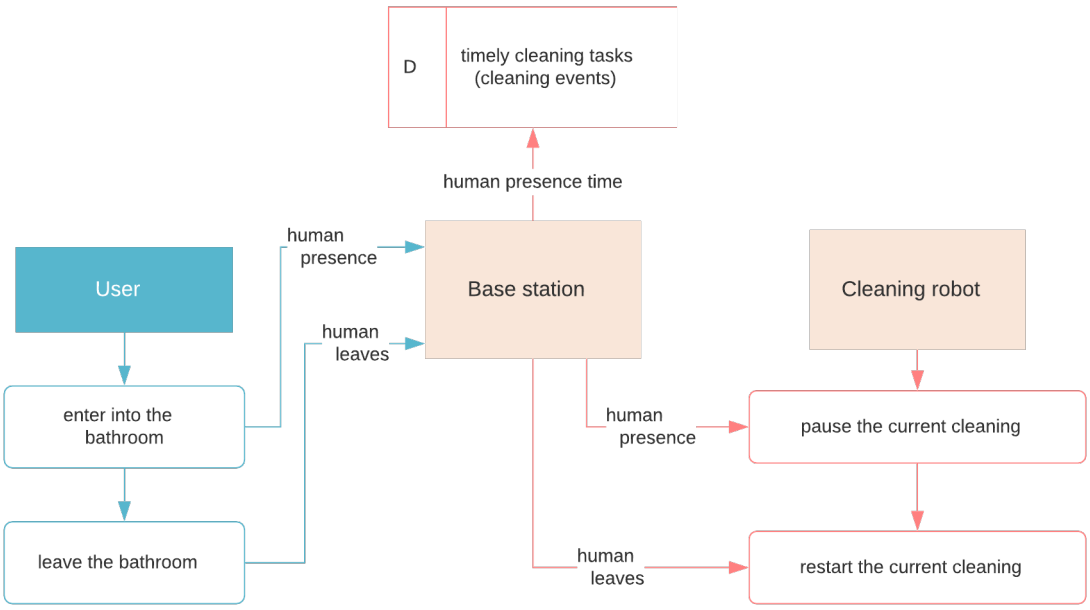


Figure 47. Human presence respond (situation 2)

3.3.4.4 Emergency response

During the cleaning process, the device may face some unexpected events and cannot continue cleaning. These problems will be sent to the user in time. (Figure 48)

3.3.4.5 Self-cleaning system monitor

In 3.3.3.3 - Expert evaluation, we introduced the physical structure of the inner self-cleaning system. The infrared sensors on the electromagnetic ladders can sense the amount of the empty boxes, while the rain sensors in the dirty water tank can reason the usage of the water. This information will be monitored by the base station. The user will be informed if the empty boxes or the clean water is exhausted (Figure 49). The sensor arrangements include infrared sensors and rain sensors.

3.3.4.6 Self-charging

According to the design requirements, cleaning robots need wireless power supplies.
Therefore, the power might be insufficient during a cleaning task. When the cleaning robot feels that its own battery is low, it will record the place information of the stopping point, and then go back to the base station to charge. After being fully charged, the robot will go back to the previous stopping point and keep cleaning. (Figure 50)

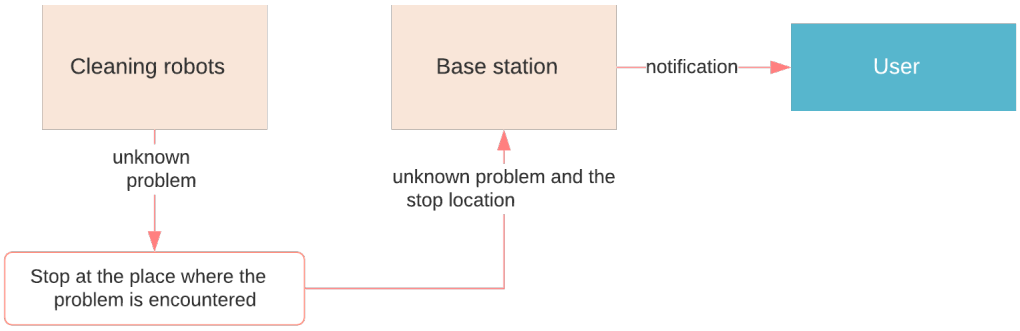


Figure 48. Emergency response data flow

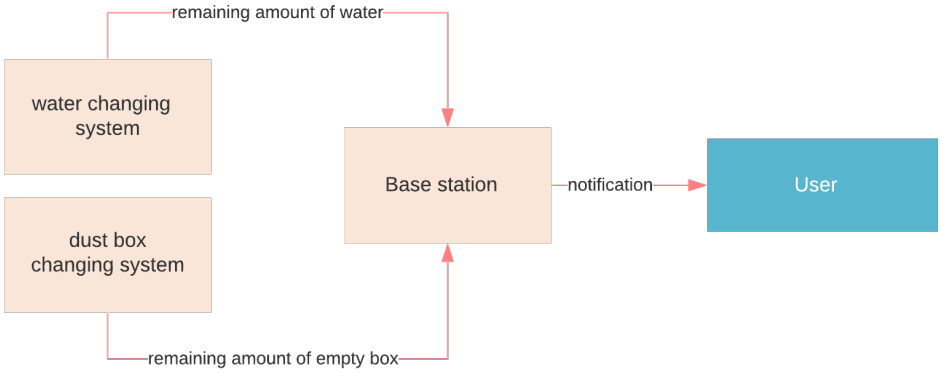


Figure 49. Self-cleaning system monitor data flow

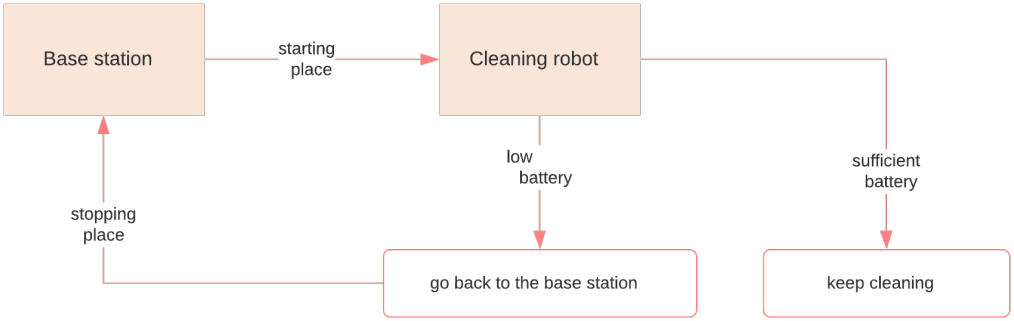


Figure 50. Self-charging data flow

3.3.5 Integrated device concept

The whole device consists of a base station, a vacuum robot, and a mopping robot. The base station contains a dust boxes changing system and a wash&ventilation system and needs a power supply. The cleaning robots can be wirelessly charged in the station.

The base station is about 40 cm high. The side lengths of the two mini cleaning robots are within 10*14*5 cm.

Figure 51 -1. Integrate device in the bathroom context

3.3.5.1 Handling dirt

A. Solid dirt

The mini vacuum robot (Figure 52) will be used to clean solid contaminants (dry hair, dust, and toilet paper, etc). The dirt will be swept by the dust brush and vacuumed into the dust box of the vacuum robot. The shape of the vacuum pad is a rouleaux triangle.

The infrared sensor in the dust box can monitor the amount of solid dirt and to reason the cleanliness of the floor. The rain sensors on the wheels can detect the wet dirt. With the help of these sensors, the device will be able to detect the place of the contaminants.

B. Wet dirt

The mini mopping robot (Figure 53) with ultra-fine microfiber mop pads will be used to mop wet contaminants such as puddles, water stain, and foam. Same as the vacuum robot, the shape of the cleaning pad is also a rouleaux triangle and there are rain sensors on the wheels to detect the wet place.

C. Mixed dirt

For the mixed contaminants (e.g. wet hair), vacuum first, the rest dirt will be mopped. In a timely vacuuming and mopping task in the early stage, the vacuum robot will scan the floor first and send the information of the wet place to the mopping robot.

3.3.5.2 Self-cleaning

The self-cleaning system is in the base station (figure 49). The dust box changing system is for the vacuum robot, and the washing & ventilation system is for the mopping robot. After each cleaning task, the robots will automatically enter into a certain system to clean itself.

A. Vacuum robot: dust box changing system

The electromagnet ladders in the base station and the magnets on the dust boxes form the dust box changing system (Figure 54). In this system, the dirty dust box will be removed from the vacuum robot and a clean box will be equipped later. Infrared sensors on the ladders can monitor the usage of the boxes, in order to notify the users to empty the full boxes.

B. Mopping robot: washing & ventilation system

After a mopping task, the mopping robot moves back to the base station. The mopping pad rotates in the cleaning pool to clean itself with the water from the clean water tank. Then, the dirty water will be pumped into the dirty water tank. At last, the ventilation fan will ventilate the cleaning pool to keep it dry. The rain sensor in the water tanks can monitor the usage of water, in order to inform the user when the clean water is used up. (Figure 55)

3.3.5.4 Other functions

A. Self-charging

When the cleaning robots go back into the base station, the charging electrode sheets below the device will match the charging interface to charge.

B. Human present detection

The human present sensor in the base station can feel the person entering into the bathroom, so that the cleaning task can be automatically suspended when someone interrupts in the bathroom.

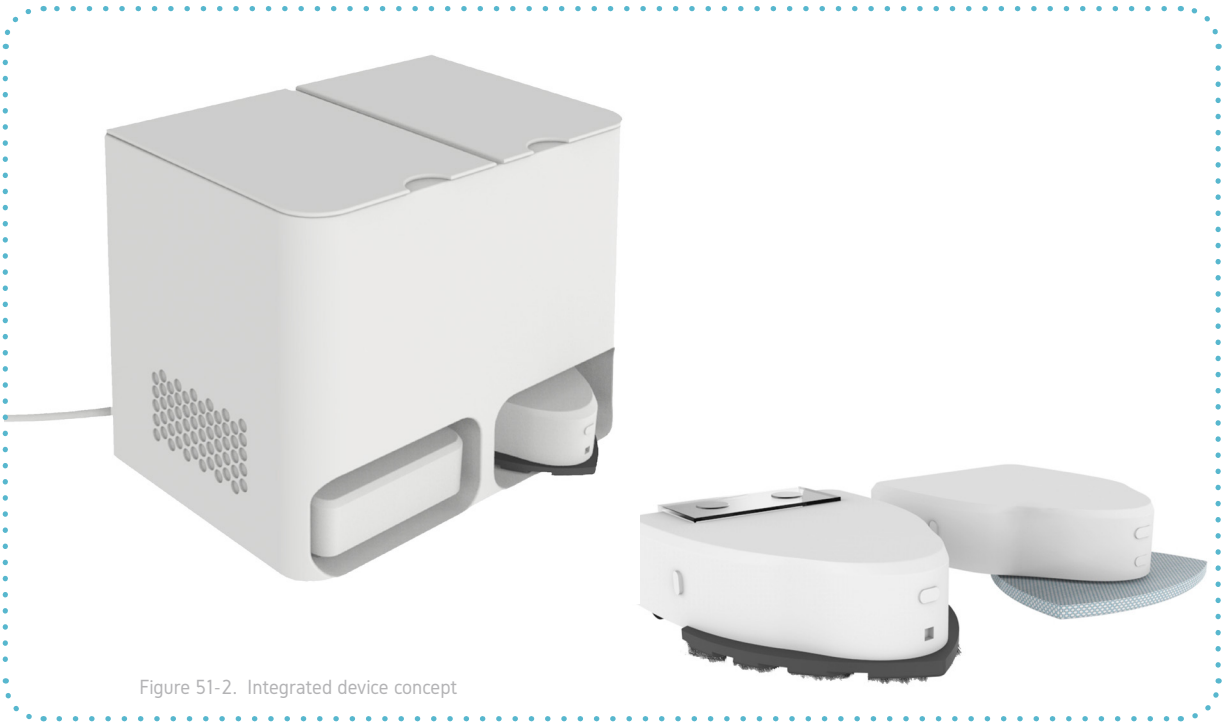


Figure 51-2. Integrated device concept

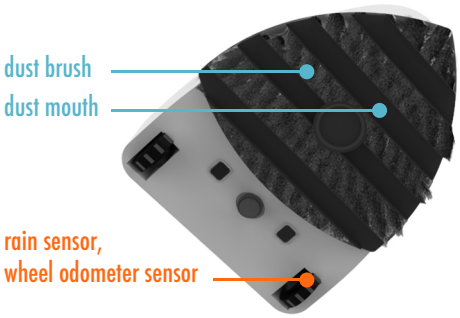


Figure 52. Mini vacuum robot

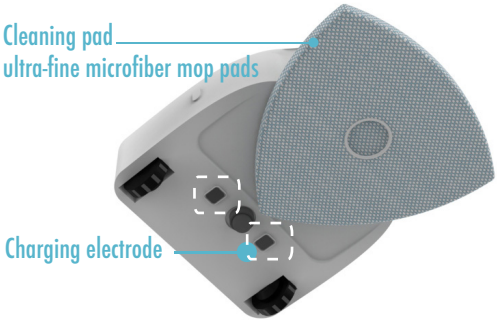


Figure 53. Mini mopping robot

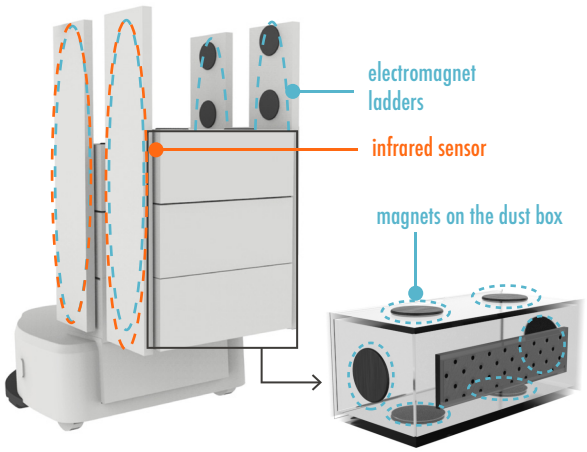


Figure 54. Inner box changing system

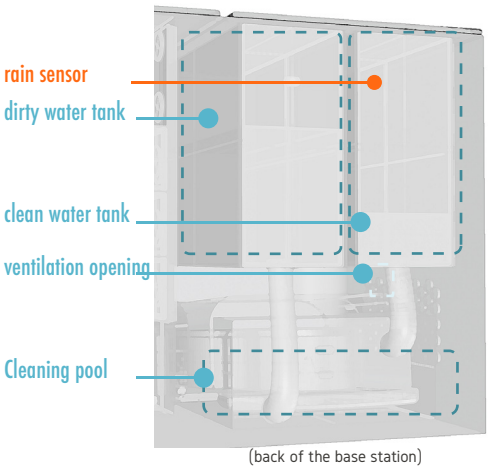


Figure 55. Inner wash & ventilation system

3.4 INTERACTION CONCEPTS

3.4.1 Objective

After getting the complete device concept, we need to design different ways of interaction between the device concepts and the human. These interaction concepts will be used for the later evaluation, in order to find the most appropriate interaction that can best reach the design goal.

3.4.2 Approach

The analysis of the context and market aspect shows that the Chinese and Dutch groups have different attitudes and acceptances for smart products. In addition, the discussion of this project is in the context of CPSs. As one of the CPSs principles (detailed in 2.2.4.3), levels of automation were chosen as the starting point of the interaction concept generation. We defined the device concepts with different automatic levels, and designed the interactions for them. In addition, we used different interaction techniques and emotional expectations to enrich the interaction concepts. Later, these concepts were detailed explained through the interaction functions and storyboards. The approach of the interaction concept development is illustrated in Figure 56.

3.4.2.1 Intelligence levels

Based on the findings in 2.3.4 - Cyber-physical system principles, the proposed reasoning model of CPSs can also be associated with levels of automation. [18] According to the characteristics of the human and the system on different levels of automatic, we designed three interaction with device in different automatic levels.

Concept 1: Interaction with the highest level of intelligence device

When the device has the automation on level 2, humans perform as executive controllers. The cyber-physical system that consists of the smart cleaner and the user has the following characteristics: 1) the smart cleaner system provides a certain extent level of automation, 2) humans control the smart cleaner system in a holistic way, 3) the starting of interaction is bilateral. The self-controlling capabilities of 2G-CPSs are enablers for it. [18]

Concept 2: Interaction with the medium level of intelligence device

On this level, humans act as system assisted task

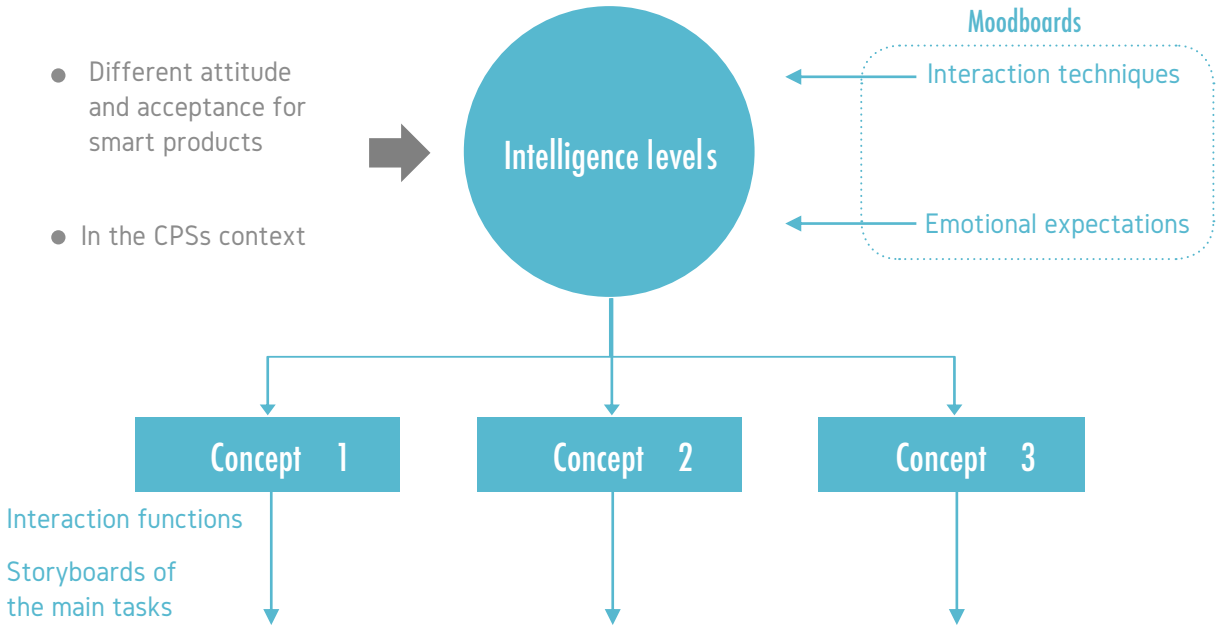


Figure 56. Interaction concepts development

performers [18], which means 1) humans and the device are considered together for executing the tasks, 2) the tasks are arranged according to the capability of humans and the device. These contain the characteristics of 1G-CPSs.

Concept 3: Interaction with the lowest level of intelligence device

Humans act as direct task performers on this level of intelligence [18]. Specifically speaking, all necessary operations are executed by humans. They also provide primary control.

3.4.2.2 Moodboards

After defining the general distinction between the interaction concepts, the next step is to refine them., we need to apply appropriate interaction techniques on the three interaction concepts. Also, the invisible emotional expectations (trustworthy, effortless) need to be considered, and it should become how the user perceives the product. The approach used is to create moodboards (Figure 57-58) to gather inspiration from smart products that use different interaction techniques, and to find approaches for achieving emotional expectations.

After the generation of the mood boards, we analyzed which elements can be taken into consideration for the envisioned interaction concepts. For instance, context-related touchscreens as the interaction panel of some conceptual smart home products, smart speakers or mobile apps to command smart devices, and physical buttons that can often be seen on home appliances. As for the emotional aspect, we found some inspirations such as using an instruction book to increase a sense of trust or language communication to increase effortlessness. The chosen techniques and inspirations for emotional expectations can be found in the 3.4.3 - Interaction concept for a detailed introduction.

3.4.2.3 Interaction functions

For finding the interaction functions, we first found the touchpoints between the human and the device from the device functions. After that, these touchpoints will be supplemented and organized by analyzing the usage process of humans (also the learning process of the device).

Figure 59 demonstrates the touchpoints related to the device functions. The physical functions only involve the device and the bathroom environment, so there is no human-related interaction. For the cognitive functions, the following touchpoints are found.

Manual starting:
- The user launches the device to start a specific cleaning task.
- The user receives the notification about the cleaning task.

Incidetal starting:
- The interaction is started by the device. When the user causes contaminants and leaves the bathroom, the cleaning robot will automatically start cleaning. The user receives the notification about the cleaning task and then decides if he/she wants to cancel it.

Scheduled starting
- The user sets a cleaning schedule.
- The user receives notification before the scheduled cleaning about removing the items on the floor.
- The user receives notification about the cleaning task.

Human presence:
- The device will pause automatically when the user interrupts the cleaning. If the user wants the device to stop the current cleaning or cancel an upcoming cleaning, he/she needs to manually stop/cancel it.

Emergency response:
- The user receives notification about the emergency.

Self-cleaning system monitor:
- The user receives notification of lacking empty dust boxes and clean water.

In addition, from the user's entire operating process (also the learning process of the machine), the interaction points are supplemented as follows:
- Before using the device, the user should install the device, and in some situations, learn the usage of the device.

To sum up, the interaction function modules are shown in Table 4.

Each interaction concept contains all these functions, but the three behave differently. The specific form of expression can be found in 3.4.3 - interaction concepts.

Interaction techniques moodboard Figure 57

Interaction techniques moodboard Figure 58

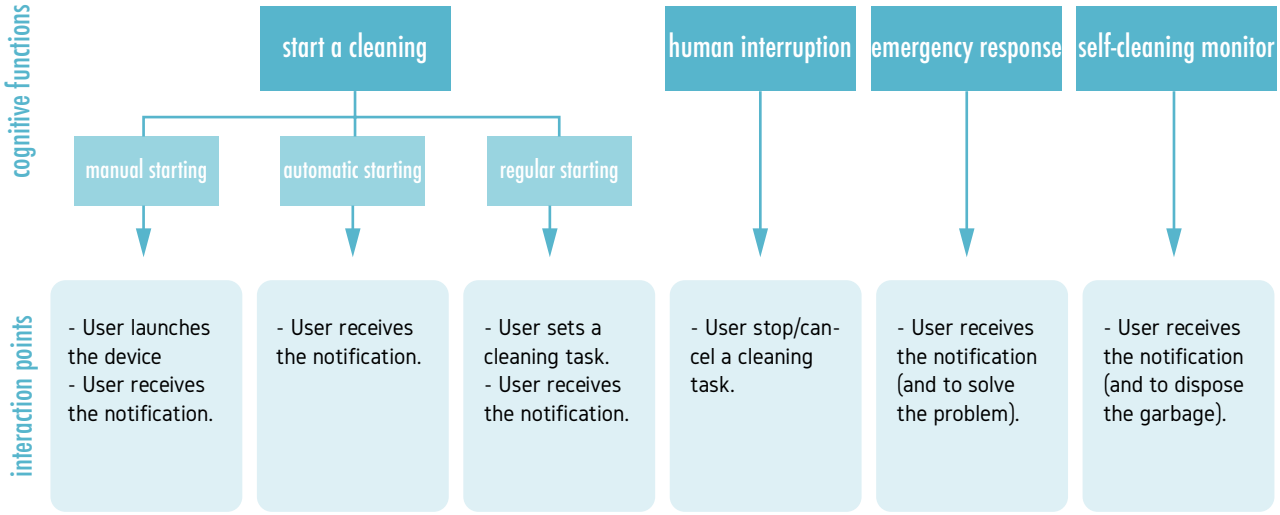


Figure 59. Cognitive related interactions

Table 4. Interaction function modules

MODULE	NAME	DESCRIPTION
PREPARETION (FIRST TIME USE)	install guidance	guide users to install the device
	usage guidance	teach users the main functions of the device
TIMELY CLEANING START & STOP	start/restart	start/restart a timely vacuum or mopping task
	pause	timely pause the cleaning task (the task can be restart)
	stop	stop the current/upcoming cleaning task (the task finishes)
REGULAR CLEANING SCHEDULE	time point	starting time
	cleaning type	vacuuming or mopping or both
	repetition	once or weekly repetited
NOTIFICATION (CLEANING HISTORY)	tasks have done	show the vacuum or mopping tasks
	cleaning time	show the time point and duration
	cleaned area	show the cleaned area
NOTIFICATION (OTHERS)	throw garbage, change water	inform the usage of dust bin and water tank
	emergency notification	inform the usage of dust bin and water tank

3.4.2.4 Interaction tasks

In order to represent the operations and the impact of the interaction functions, we combed a series of operational tasks. These tasks contain the main functions that can create a complete user experience of using this product. In addition, it also contains the learning process of the smart device.

Specific tasks include:
1. Install the device
Description: Before use, the user needs to install the device and to learn how to use the device.

Interaction Functions:
Install guidance, usage guidance.

2. Try out the device
Description: The user launches a cleaning task manually the first time.

Interaction Functions:
manually start, cleaning completed notification.

3. Start a incidental cleaning task
Description: The user soiled the bathroom floor and want to incidental clean it.

Interaction Functions:
automatically start (early stage), cleaning completed notification.

4. Cancel a incidental cleaning task
Description: The device starts automatically, but the user wants to stop/cancel it.

Interaction Functions:
stop/cancel a cleaning task.

5. Set a schedule
Description: The user wants the device to clean the entire floor every Saturday.

Interaction Functions:
Set a cleaning schedule.

6. Garbage disposal/emergency response
Description: The garbage needs to be disposed of/ unknown problem needs to be solved. Since the interactions involved in these two functions are both reminding issues and to ask the user to solve the problems, we put them in the same task to discuss.

Interaction Functions:
garbage disposal notification, emergency notification.

7. Start a incidental cleaning (after a period of time)
Description: The user soiled the bathroom floor and want to incidental clean it. Since the device has learned the pattern of the user, the starting of a incidental cleaning might be different.

Interaction Functions:
automatically start (later stage), cleaning completed notification.

3.4.3 Interaction concepts

3.4.3.1 Concept 1

Intelligence

Concept 1 is base the device concept with the highest level of intelligence. Generally speaking, the smart cleaner can automatically start a cleaning task and to clean the reasoning contaminated place. For the scheduled cleaning tasks, the device can decide the cleaning time by reasoning the cleanliness of the bathroom floor. Users can teach or control the device by manually cancel or start a cleaning task. The starting of interaction is from both the device (e.g. automatic cleaning) and the user (e.g. manual operations).

Interaction techniques and emotional expression

The main interaction technique used in this concept is the touchscreen and facial recognition. The backside of the touchscreen is a nano strip panel, so it can be easily stick on or take off from the wall. It will be installed at the outside of the bathroom door and light up when people approach. In this way, users will only notice or use it when approaching the bathroom. Therefore, the device has more autonomy to take care of the bathroom cleanliness. Users will not be affected too much at the same time. With facial recognition, the device will be able to recognize a specific user. Therefore, it can better know the user's behavioral pattern and to offer a more personalized cleaning service for the user.

Trustworthy:
- An instruction to teaching installing and using the device at the beginning.
- Every time the user approaches the device, he/ she can directly see the real-time or previous cleaning information.

Effortless:
- The device will automatically clean the bathroom

after the user leaves the bathroom. The cleaning time and place will gradually be accurate.
- The device is installed at the door of the bathroom, so it will not bother the user at other times.

3.4.3.2 Concept 2

Intelligence

Concept 2 is based on the device concept with a medium level of intelligence. Users start incidental cleaning tasks, the device follows the instructions. Since the device can detect the contaminants, in other words, reason the cleanliness of the bathroom, it will be able to give suggestions on arranging the cleaning tasks. In this way, users and the device work together to take care of the bathroom cleanliness.

Interaction techniques and emotional expression

The main interaction technique used in this concept is voice control and a mobile app. When the user is in the bathroom, he/she can control this device directly via voice by some keywords. The base station will give viable feed forwards and feedbacks. Besides, users can also use the mobile app to achieve all the functions when they are not in the bathroom or do not want to speak.

Trustworthy:
- The important decisions are done by the user.
- Detailed guidance.
- Incidental and obvious voice feed forwards and feedbacks. The user will not miss important notifications.
- The mobile app shows detailed information and has the entire functions. The user can check the conditions or start a task anytime anywhere.

Effortless:
- The device will give advice to the user about the cleaning tasks arrangement. The user can deal with it with one click.

3.4.3.3 Concept 3

Intelligence

Concept 3 is based on the concept with the lowest level of intelligence. The device will follow the commands given by the user. The user is the primary controller to manage the bathroom cleanliness. The device makes detailed records of human instructions.

Interaction techniques and emotional expression

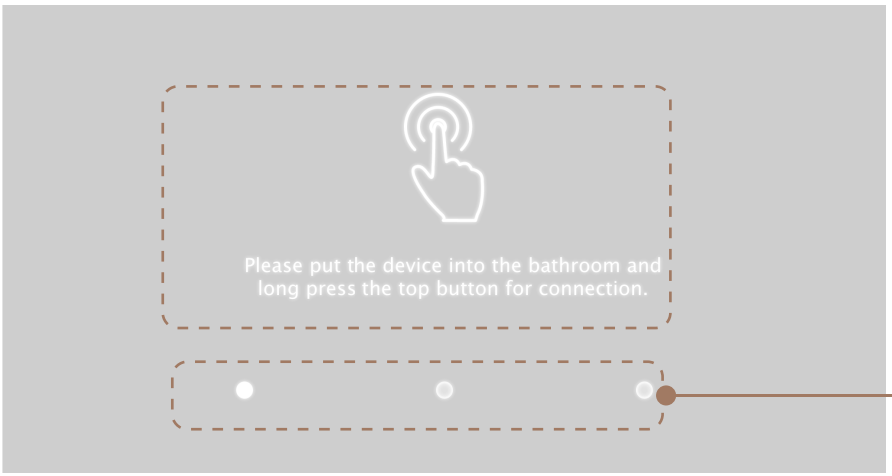
The main interaction technique used in this concept is remote control and a mobile app. The remote control contains the major cleaning functions and can be placed in an easy-to-reach place near the device. The mobile app covers comprehensive functions and allows the user to manage the tasks remotely.

Trustworthy:
- The remote control is a traditional and reliable way of interacting.
- All the decisions are made by the user.
- All the operations are recorded.

Effortless:
- Easy to install.
- No learning stage at the beginning.

Interaction concept 1

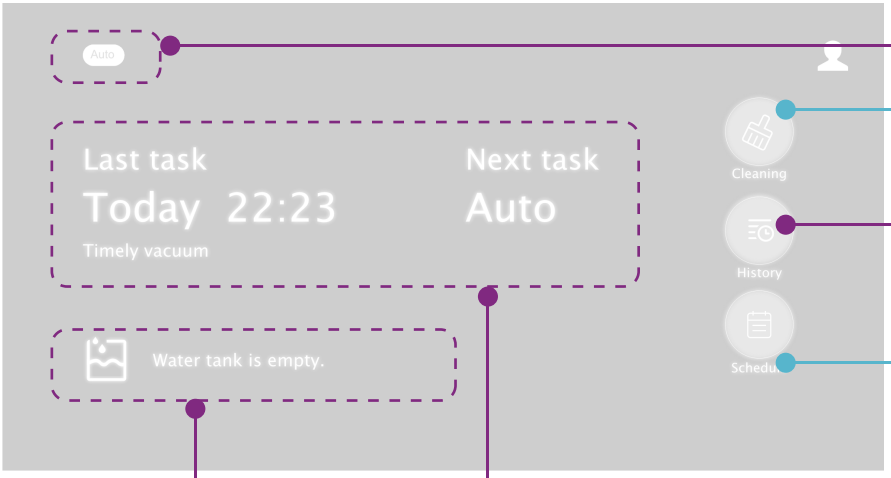
PREPARETION



PREPARETION

Three steps:
1. connect the device and the touchscreen
2. install the device at the outside of the bathroom door.
3. facial recognition

DEFAULT INTERFACE



The device is in automatic mode

MANUAL CLEANING

Users can manully start a cleaning.

CLEANING HISTORY

The history cleaning time, robot type, and cleaned place

SET A SCHEDULED CLEANING

Users can manully set a scheduled cleaning.

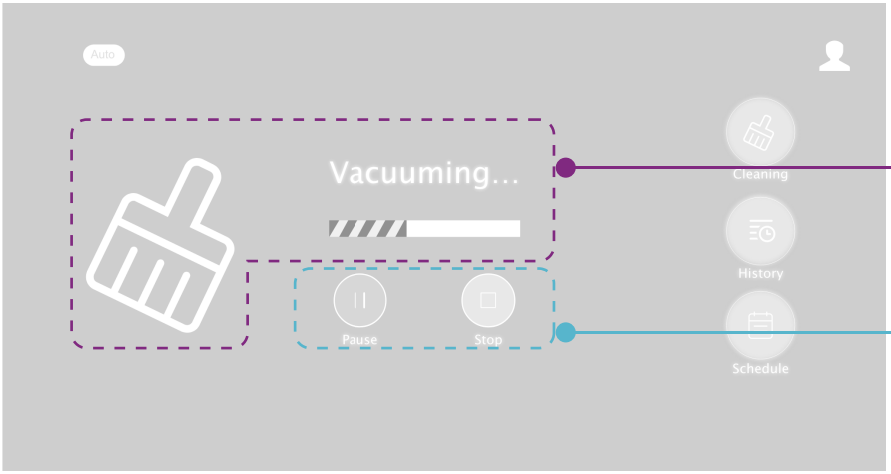
NOTIFICATION (OTHERS)N

Blinking icon and text description

OTIFICATION (LAST/NEXT CLEANING)

The cleaning type and time of the last and next cleaning. If no regular task recently, next task will be shown as 'auto'.

DURING CLEANING

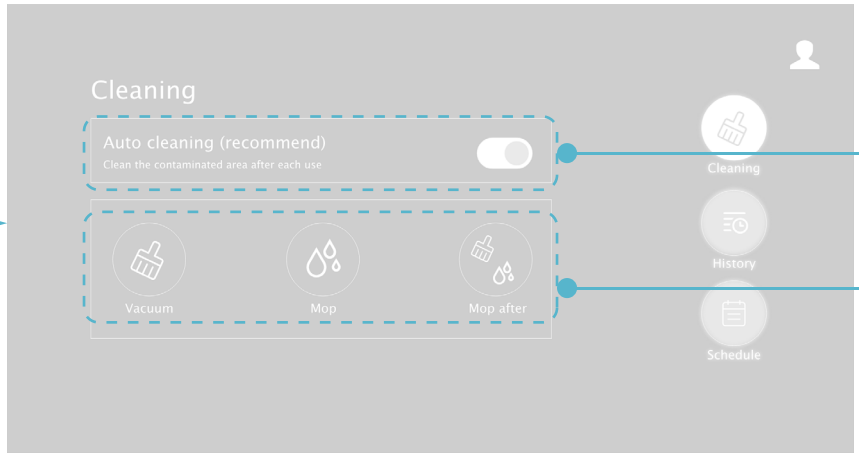


NOTIFICATION (CURRENT CLEANING)

Using obvious icon to show the current cleaning tasks. The progress bar shows the expected cleaning process.

PAUSE/STOP THE CLEANING

MANUALLY START A CLEANING



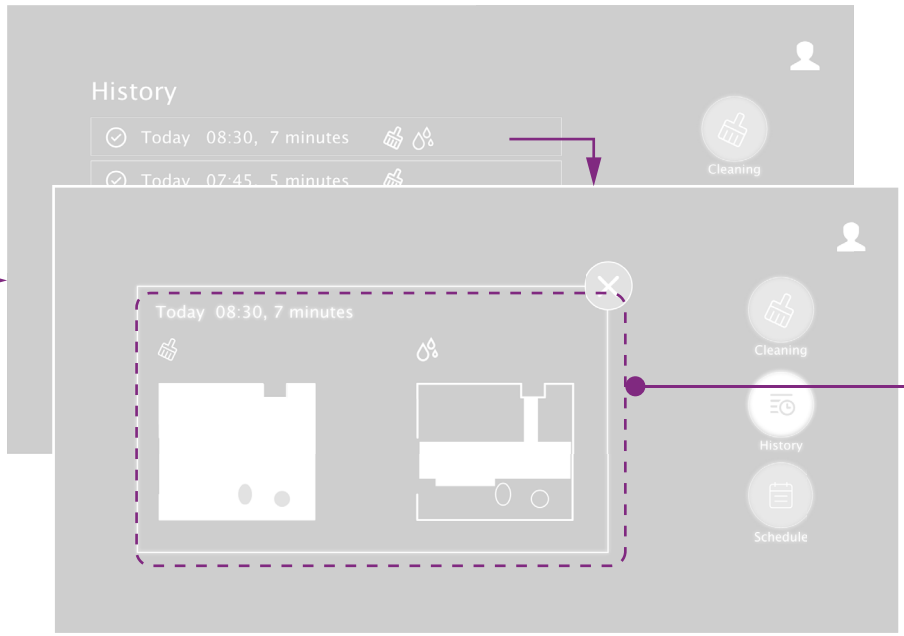
AUTOMATIC MODE

The incidental cleaning mode is on by default.

MANUAL CLEANING

Three cleaning types can be chosen:
1. vacuum only
2. mop only
3. mop after vacuum.

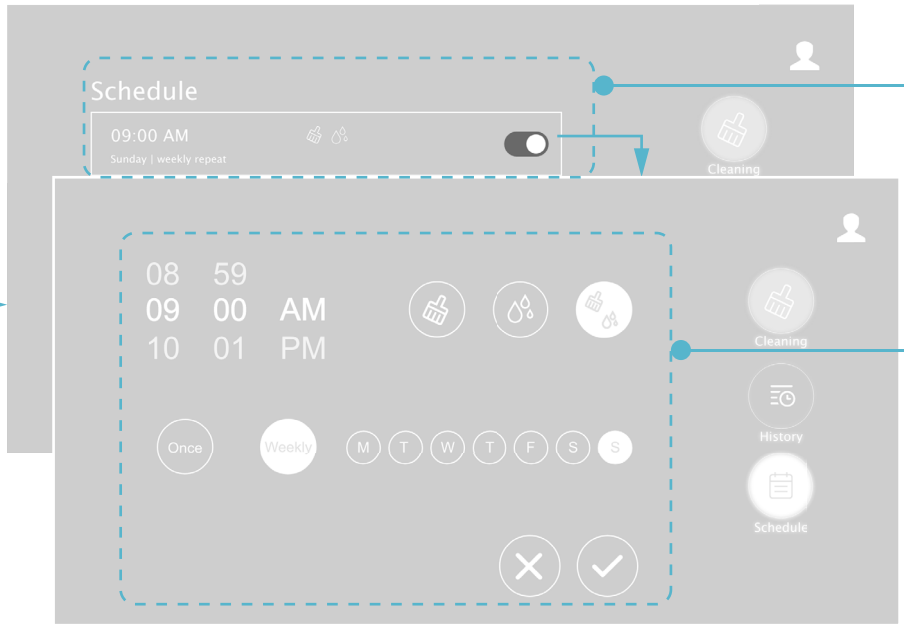
CLEANING TASK HISTORY



CLEANING HISTORY

A detailed cleaning history, contains the robot type, cleaning time, and cleaning area of the recent cleaning tasks.

SET A SCHEDULED CLEANING



CLEANING SCHEDULE

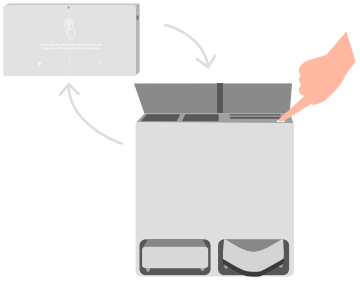
An overview of the cleaning schedule. Users can easily edit the tasks.

SET A SCHEDULED CLEANING

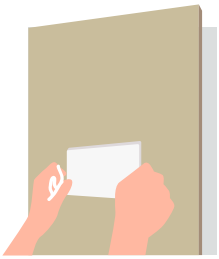
Manually set a scheduled cleaning task by choosing time, robot type and repetition mode.

Interaction concept 1

STEP 1
Install the device



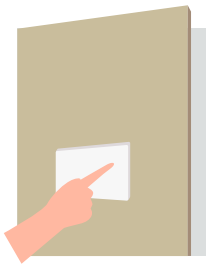
1. Follow the guidance to connect the devices.



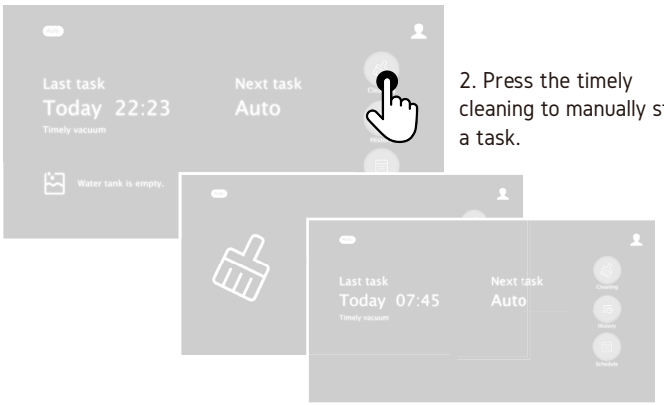
2. Put the touchscreen on the door.

3. Enter face information

STEP 2
Try out the device (manually start)



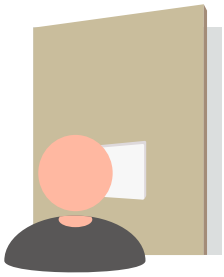
1. When the user approached, the touchscreen lighted up.



2. Press the timely cleaning to manually start a task.

3. During the cleaning, the screen shows the information of the task.

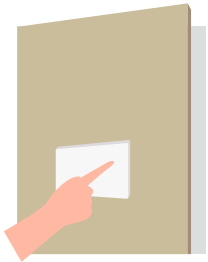
STEP 3
Incidentally start (early stage)



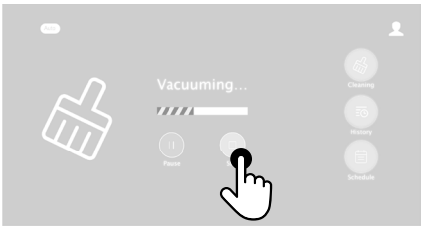
1. The user combed hair in the morning and wants to clean the hair on the floor.

2. After leaving the bathroom, the user found the cleaning task incidentally starts.

STEP 4
Cancel an incidental task

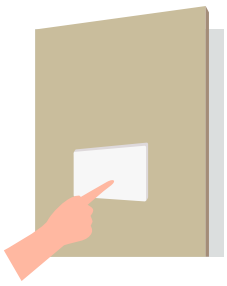


1. The user left the bathroom without causing any contaminants, but found the device automatically start.

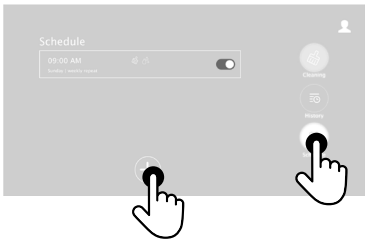


2. The user stopped the task manually.

STEP 5
Set a scheduled cleaning

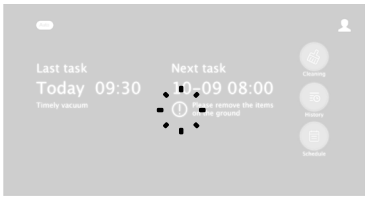


1. When the user approached, the touchscreen lighted up.



2. The user could press schedule to check the existed schedule.

3. The user could edit the existed tasks or add a new regular cleaning task.

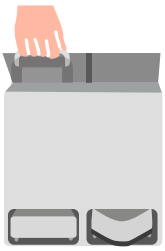


4. The day before the scheduled cleaning, the screen shows notification to let the user remove the small items on the floor.

STEP 6
Garbage disposal/ Emergency response

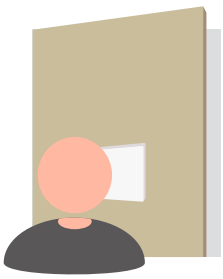
1. When the user approaches, the touchscreen lights up.

2. The icon blinked to inform the user that water needed to change.



3. The user changed the water.

STEP 7
Incidentally start (later stage)

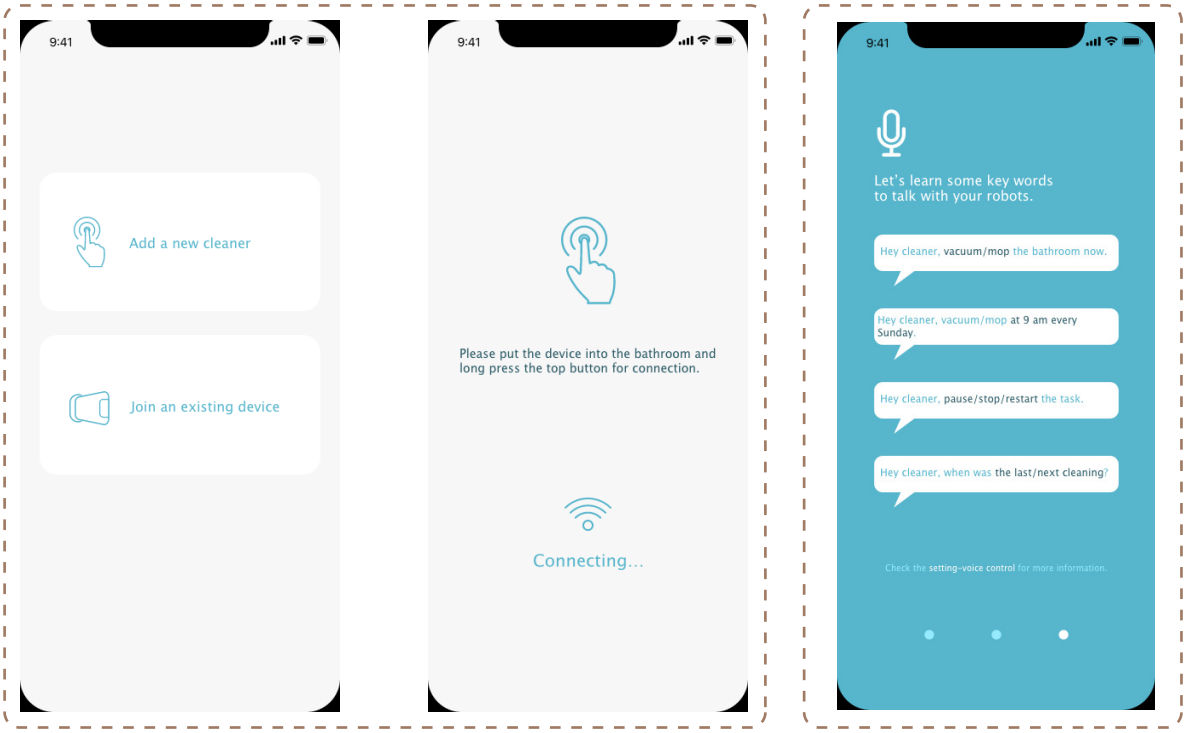


1. The user contaminates the bathroom and leaves.

2. The device automatically starts and only cleans the contaminanted place.

Interaction concept 2

PREPARETION

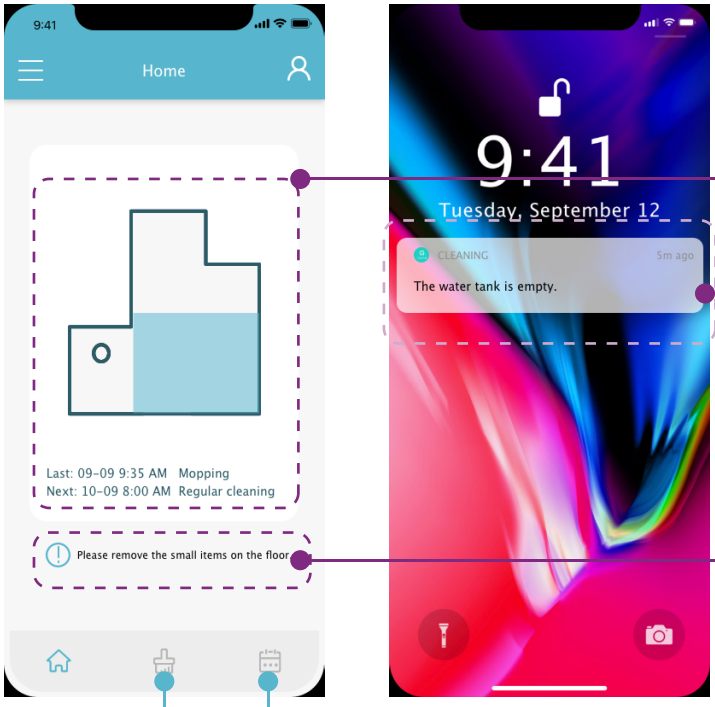


PREPARETION

Install guidance:
1. Search the device.
2.connect the device.

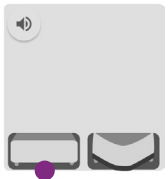
Usage guidance:
1. How to use the cleaning schedule,
2. Common voice control keywords.

DEFAULT INTERFACE



NOTIFICATION (LAST/NEXT CLEANING)

The cleaning type, time and range of the last&next cleaning. If no scheduled task recently, next task will be shown as 'auto'.



NOTIFICATION (OTHERS)

Notification will be shown on the default interface of the mobile app, notification bar of the cell phone, also through voice feedback.

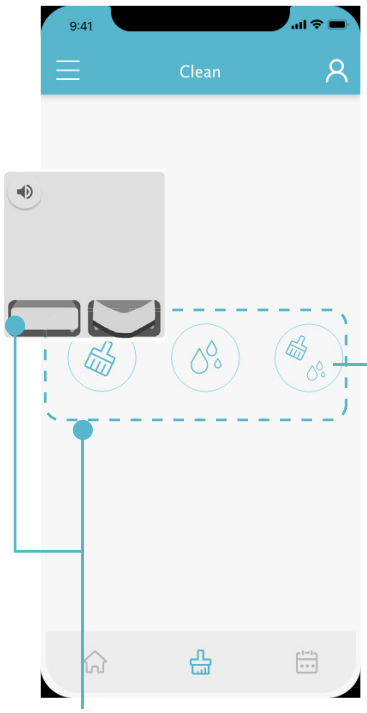
MANUALLY CLEANING

Users can manually start a cleaning.

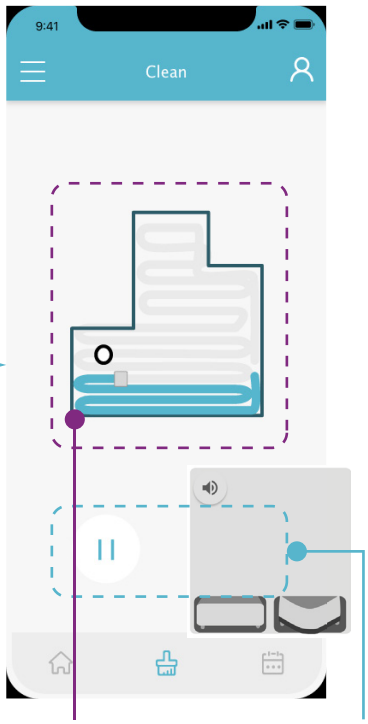
SET A SCHEDULED CLEANING

Users can manully set a scheduled cleaning.

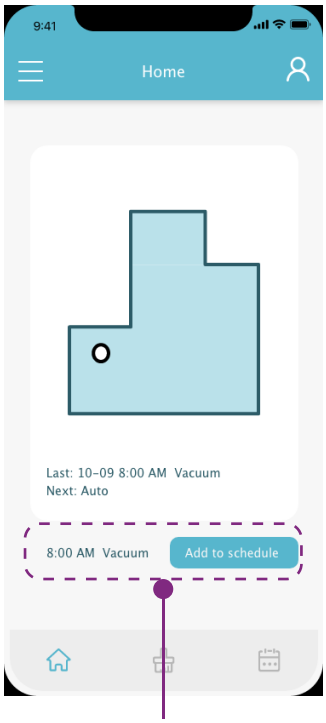
MANUALLY START A TIMELY CLEANING



DURING CLEANING



AFTER CLEANING



MANUALLY CLEANING

Start the following task by voice or mobile app
1. vacuum only
2. mop only
3. mop after vacuum.

NOTIFICATION (CURRENT CLEANING)

Illustrate the planned cleaning route and the current cleaning process.

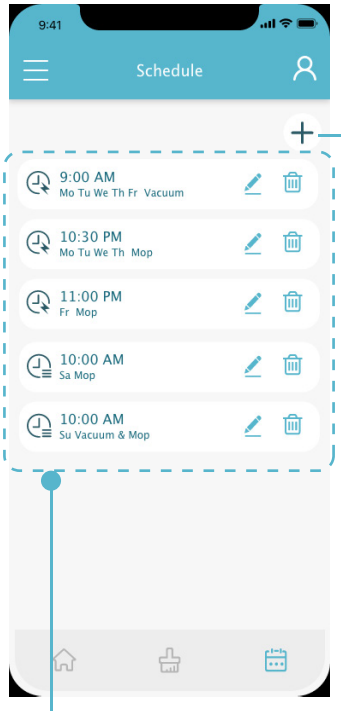
PAUSE/STOP THE CLEANING

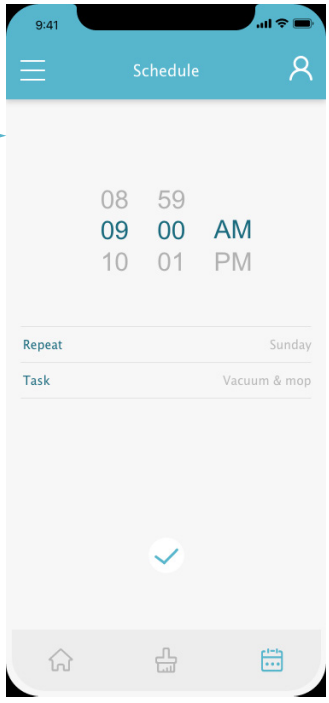
User can use the mobile app or voice to pause/stop the current cleaning task.

NOTIFICATION (ADVICE)

When the device found a possible cleaning event, it will advice user to add the task into the schedule.

SET A REGULAR CLEANING





CLEANING SCHEDULE

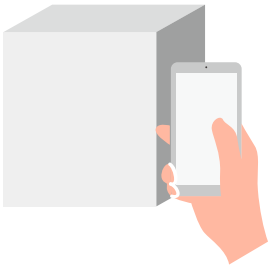
An overview of local and global cleaning (distinguished by different icons). Users can easily edit the tasks.

SET A REGULAR CLEANING

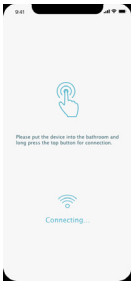
Manually set a scheduled cleaning task by choosing time, robot type and repetition mode.

Interaction concept 2

STEP 1
Install the device



1. Scan the QR code on the device to download the app.



2. follow the instruction to install the device.

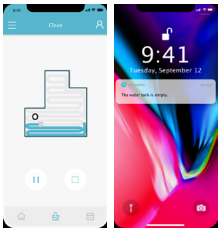
3. learn how to use the device (e.g. voice control keywords)

STEP 2
Try out the device (manually start)

1.1 The user can ask the base station: 'hey cleaner, vacuum the bathroom!'

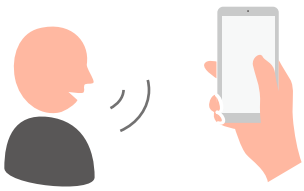
1.2 After the cleaning, if there is no dirt on the floor, the device will give feedback 'your bathroom is very clean'

2.1 The user can also use the mobile app to start a task.

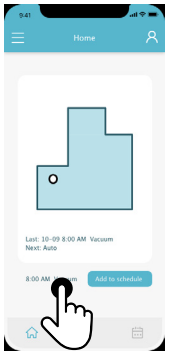


2.2 The user can view the details of the cleaning task from their mobile phone.

STEP 3
Incidentally start



1. The user combs hair in the morning and wants to clean the hair on the floor, the first time he/she should start the device manually.

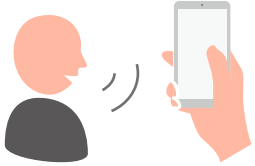


2. When the device detects ground contaminants and forms a cleaning event, it asks the user whether to add it to the schedule.

3. Next time, the cleaning will start automacitally.

STEP 4
Cancel an incidental task

1. Before an incidental cleaning, if the user is in the bathroom, the device will give a feedforward 'cleaning will start after you leave'



2. The user can cancel it by saying 'hey cleaner, cancel it', or use the mobile all to cancel.

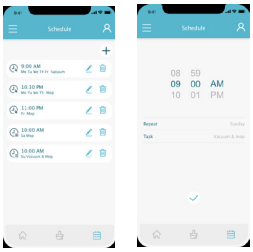
3. The device will then give a feedback, 'cleaning task has been canceled.'

STEP 5
Set a scheduled cleaning

1.1 The user can ask the base station: '"Hey cleaner, vacuum an mop the bathroom every Sunday morning at 9 am.'

1.2 The device will give feedback 'a schedule has been set. Vacuum, 9 am, every Sunday.'

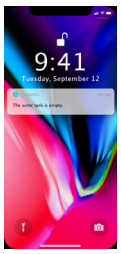
2.1 The user can also use the mobile app to set a scheduled cleaning.



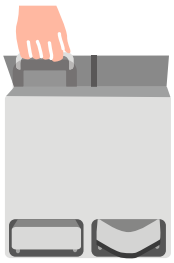
2.2 Since the user might already add some tasks in step 2, he/she can manage the tasks by the mobile app.

STEP 6
Garbage disposal/ Emergency response

1.1 When someone enters the bathroom, the device will alert (e.g.)'please change water'

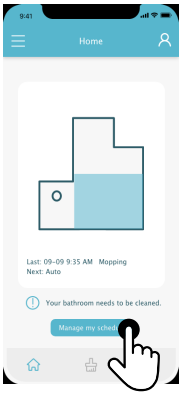


1.2 The user will also receive a notification on the mobile app.

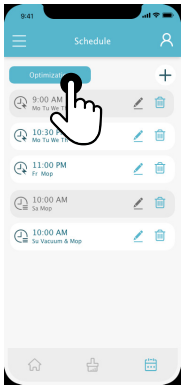


2. The user changes the water (or solve the problem).

STEP 7
Incidentally start (later stage)



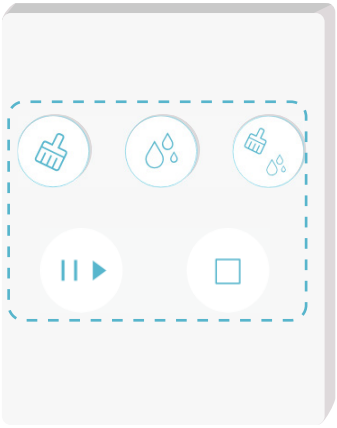
1. If the robot detects too many/little contaminants during the cleaning, it will suggest you to manage the schedule on the mobile app.



2. The app will give suggestions on optimizing the tasks.

Interaction concept 3

REMOTE CONTROLP



MANUAL CLEANING

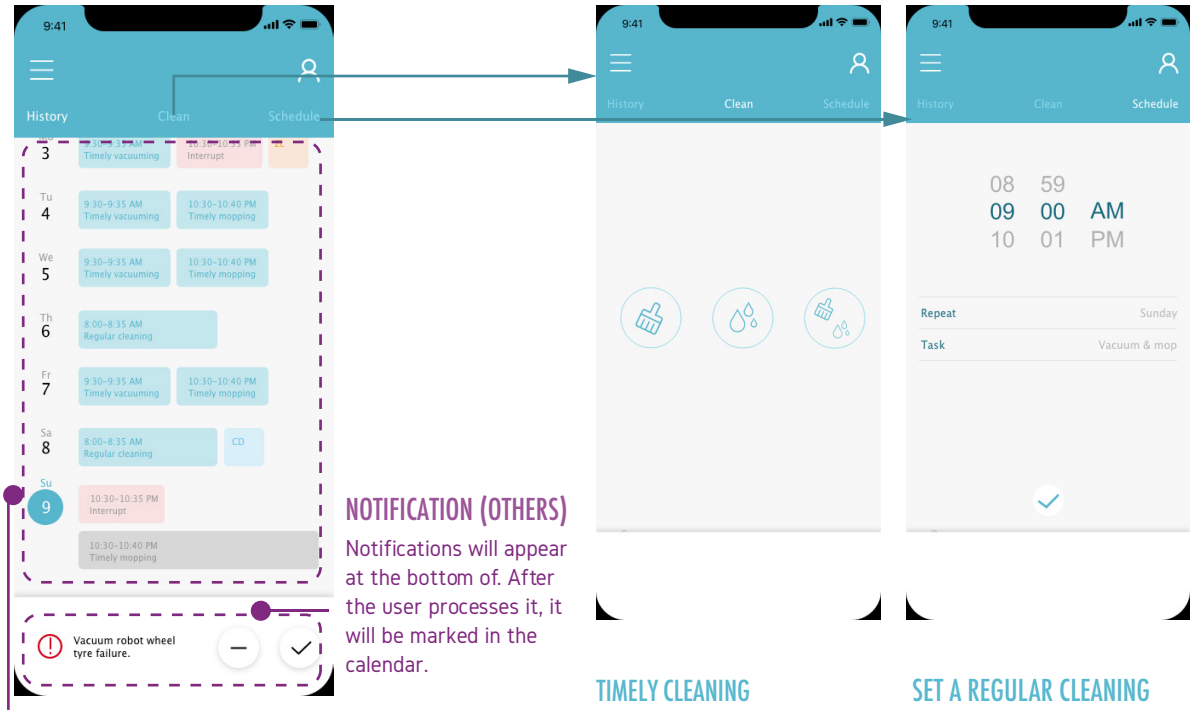
manually start/re-start a cleaning task, pause/stop the current task.

REPARATION

PREPARETION

Install guidance:
1. add a new cleaner.
2.connect the devices

DEFAULT INTERFACE



NOTIFICATION (OTHERS)

Notifications will appear at the bottom of. After the user processes it, it will be marked in the calendar.

NOTIFICATION (CLEANING AGENDA)

Show the previous and upcoming cleaning tasks in the form of a calendar. Different colors represent different actions, e.g. green-finished tasks, gray-un-comping tasks, red-unfinished tasks, blue-others.

TIMELY CLEANING

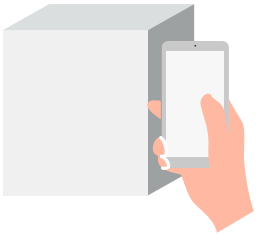
Manually set a timely cleaning.

SET A REGULAR CLEANING

Manually set a regular cleaning task by choosing time, robot type and repetition mode.

STEP 1
Install the device

1.1 The user can directly use the remote control.

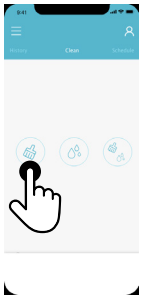


2.1 Scan the QR code on the device to download the app.

2.2 follow the instruction to install the device.

STEP 2
Try out the device (manually start)

1.1 The user can directly launch a task by the remote control.



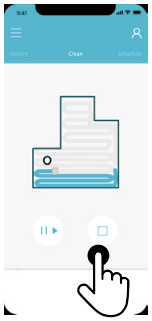
2.1 Use mobile app to start the task.

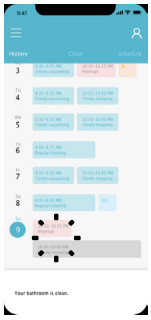
STEP 3
Incidentally start

Same as step 2. Since the device completely follows the command of the user, it will not automatically start without permission.

STEP 4
Cancel a task

1.1 The user can directly stop a task by the remote control.

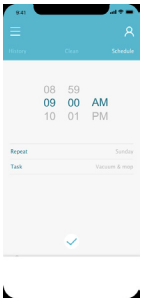




2.1 Use mobile app to stop the task.

1.2 & 2.2 The interruption will be recorded.

STEP 5
Set a scheduled cleaning



The user can only use the mobile app to set a scheduled cleaning.

STEP 6
Garbage disposal/ Emergency response

The lights on the device give a signal when the problem occurs

The problem is also notified on the mobile app. After the user solves the problem, the action will be recorded.

STEP 7
Later stage

Same as step 2. Since the device completely follows the command of the user, it will not automatically start without permission.

4. EVALUATION

4.1 INTRODUCTION

In the previous phase, we have produced a device concept of the envisioned smart bathroom cleaner, as well as three interaction concepts based on the device with different intelligence levels. However, it is unclear what experience these interaction concepts will bring to the target groups. The overall aim of this part is to evaluate the interaction concepts, and to find suitable interactions between this smart bathroom floor cleaner and the Chinese and Dutch target users who have different interest and acceptance of smart products.

4.2 APPROACH

The evaluation phase consists of two parts. The first is to generate one concept from the previous three interaction concepts. Evaluation sessions with the target users were done to gain comments and feedback on the three interaction concepts. After analyzing the result, we have the final concept. The second part is to evaluate the final concept. A session with design students was done to test the final concept. Finally, an overall comment on the final solution is obtained to provide a source for a subsequent recommendation. Figure 61 shows this process.

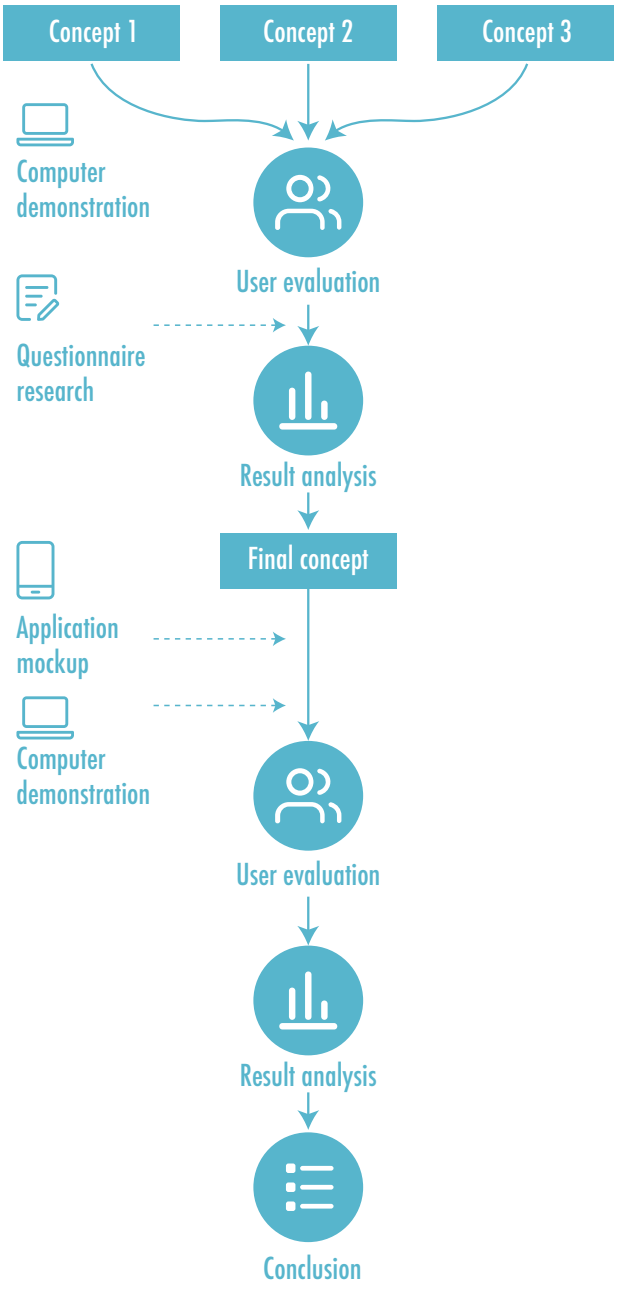


Figure 61. Evaluation process

4.3 THREE INTERACTION CONCEPTS EVALUATION

4.3.1 Approach

Preparations

- CAD models and animations to introduce the context and to demonstrate the device concept.
- Hi-fi interaction prototypes and animations to demonstrate the interaction concept.
- Storyboards to show different scenarios to the participants understand the context of each interaction.
- questionnaire to collect feedback about their the trustworthy and effortless on each step, and the overall impression of the three interaction concepts.

The detailed stimulate can be found in Appendix E.

Sample

5 Chinese and 5 Dutch random participants, aged from 20 to 27.

Inquire questions

RQ1. To what extent do the participants feel trustful and effortless of each concept (or interaction element) when interacting with this smart bathroom floor cleaner?

RQ2. What interaction fits the usage and cleaning habits of the two groups of the target users? Is there any difference?

Procedure

Participants have explained the topic of the project and were asked to recall their experience of using the bathroom before the test. The picture of the bathroom environment was shown as a stimulus for understanding the context.

CAD models of the smart cleaner demonstrated to introduce the physical part of the device concept. The introduction includes:
1. The size and shape of each component.
2. How the robots clean solid/wet contaminants.
3. Self-cleaning systems for the vacuum robot and the mopping robot.

Animations and verbal description were used to explain the evaluation-related cognitive functions (Figure 62), which includes:
1. Automatic starting logic.
2. How the robot detects solid/wet contaminants.
3. How the self-cleaning system monitors itself.
4. Self-charging.

After that, we demonstrate the prototype on the laptop screen or cell phone of each concept to the participants. Each test consists of the following steps:
Step 1: Install the device.
Step 2: Try out the device.
Step 3: Start an incidental cleaning task.
Step 4: Cancel an incidental cleaning task.
Step 5: Set a scheduled cleaning schedule.
Step 6: Garbage disposal/emergency response.
Step 7: Start an incidental cleaning after a long term of use.

During the test, we encourage the participants to think out loud. They can ask questions for anything unclear. After demonstrating each step, they were asked to comment and score the trustworthy and effortless of the interactions in this step and to fill in the questionnaire from -2(the least) to 2 (the most). They could always adjust the previous scores.

Repeat the steps for all the concepts. The testing orders of the three concepts were changing during the test to avoid the influence of the order.

At last, the participants were asked to rank the three concepts by their preferences and explain the reasons behind. Each test takes 45 to 60 minutes.

Data collection

The data collection can be divided into two categories. The qualitative data that refers to their problems, comments, and recommendations during the test. The quantitative data refers to the trustworthy and effortless degrees they gave to each step and the participants' preferences order of the three concepts.

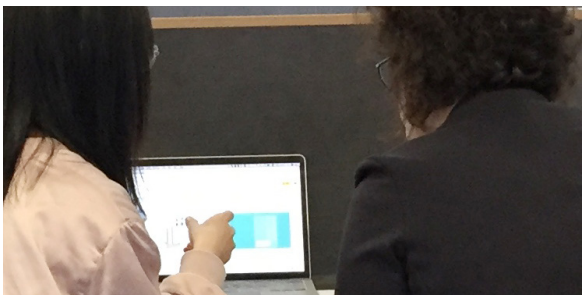


Figure 62. Introducing the device concept to a participant

4.3.2 Findings

The analysis of the results consists of two parts. The first is all the participants' feedback on the concepts. The second is to compare the feedbacks between the Chinese and the Dutch participants.

4.3.2.1 Findings on the concepts

The analysis of each concept will be discussed from the trustworthy and effortless aspects. The main problems and insights were clustered according to the seven test steps. At last, the overall comments summarized the feedback of the concept.

Concept 1

Before using the device (Step 1), the participants are confused about the install steps, and cannot directly understand or trust the operation logic of the device, so the score of the trustworthy is low. However, since the device contains an advanced facial recognition function, they have a high expectation on the device and think all the preparations are necessary.

During the early stage of use (S2-S6), the participants have a positive attitude towards the concept. Several participants mentioned that the position of the device is good because it is related to the bathroom context. They can handle the bathroom-related things directly in (near) the bathroom. Although they give a high score on the trustworthy, the participants are still worried about the cleaning logic of the device, which contains the doubts such as 'how can it reason a random place', 'how can it form cleaning events if I do not have a bathroom usage pattern', 'I feel the device is easy to lose control'. Besides, the experience of setting the cleaning schedule (scheduled cleaning) is not very effortless. Participants regard it as a smart device and expect it doesn't need care, but actually, the product cannot automatically move the items before scheduled cleaning. Thus, the effortless score of step 5 is low.

For the later stage of use (S7), the participants agree that using it to clean the bathroom could be effortless. However, the comment is based on a good cleaning ability and high accuracy of reasoning the cleaning time and place.

To sum up, the participants do not fully trust this concept because of the uncertain cleaning algorithm, but they agree that this concept is promising to offer an effortless solution for bathroom floor cleaning in a long term.

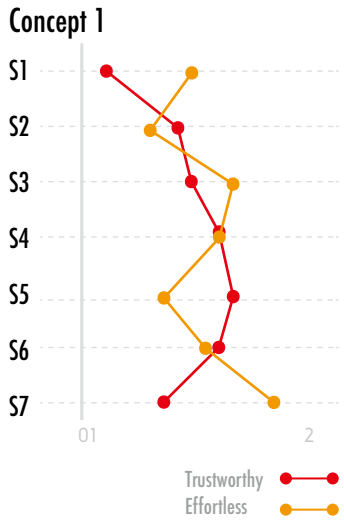


Figure 63. Concept 1: scores of each step

Concept 2

Before using the product (S1), the participants trust this concept since the workflow is clear and it is common to use a mobile app to install a smart device. The score of the effortless is relatively low because there are lots of things to learn (especially the keywords of the voice control).

During the early stage of use (S2-S6), the discussion on this stage is mainly about interactive technologies, namely mobile app and voice control. Using the mobile app to start a incidental cleaning task is troublesome since it takes time and effort to find the cell phone and the app, but it is trustworthy for the complex information and settings. The considerations for voice control also contain positive and negative sides. Positive points:

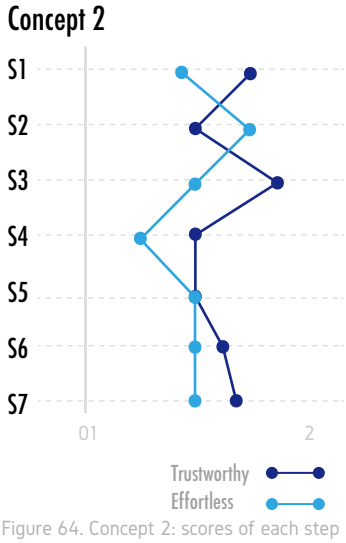


Figure 64. Concept 2: scores of each step

1) the voice feedforward and feedback are direct and trustworthy. Negative points: 1) it takes time to remember the voice command; 2) not all the participants want to speak in the bathroom; 3) they worry about the accuracy of speech recognition; 4) uncertain and unclear about the feedbacks after inputting a complex instruction by voice.

For the later stage of use (S7), the participants gave comments from the perspective of intelligence. In general, the cleaning logic of the device is understandable. But the participants hope it can be smarter and more active. For instance, when finding a place for improvement, the device should actively adapt itself, rather than asking the user for advice.

To sum up, using a mobile app to interact meets the participant's usage habits, especially for dealing with complex information. Voice can be a good interaction for incidental feedback, but the scope of it needs to be more strictly defined. Although the user can directly understand the cleaning logic of the device, they hope it can be more intelligent and less disturbing.

Concept 3

Before using the product (S1), the participants quickly point out the storage problem of the remote control. Although they do not need to install the device (if they do not download the mobile app), they still regard it as a troublesome interaction. For the trustworthy, because the participants are very familiar with the remote control, they gave a high score on it.

During the early stage of use (S2-S6), incidental starting a cleaning task by remote control, or in other words, by physical buttons that can be easily reached, is effortless and trustworthy. But for achieving other functions such as setting a schedule, it will be more troublesome to download an app in this stage. It is worth noting that using a light on the device for reminding issues are welcomed for most of the participants.

For the later stage of use (S7), this concept receives a negative evaluation since it takes time and effort to operate.

In general, the overall concept is not very promising. But some of the interaction elements (e.g. physical button for incidental control, lights on the device for reminding) can be taken into consideration.

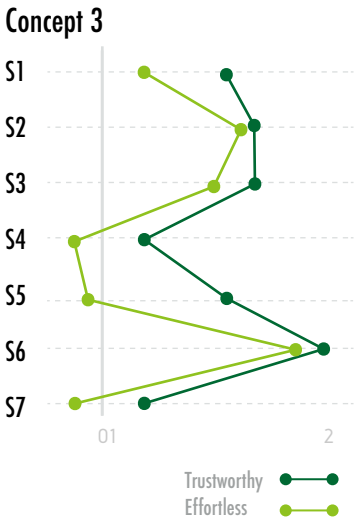


Figure 65. Concept 3: scores of each step

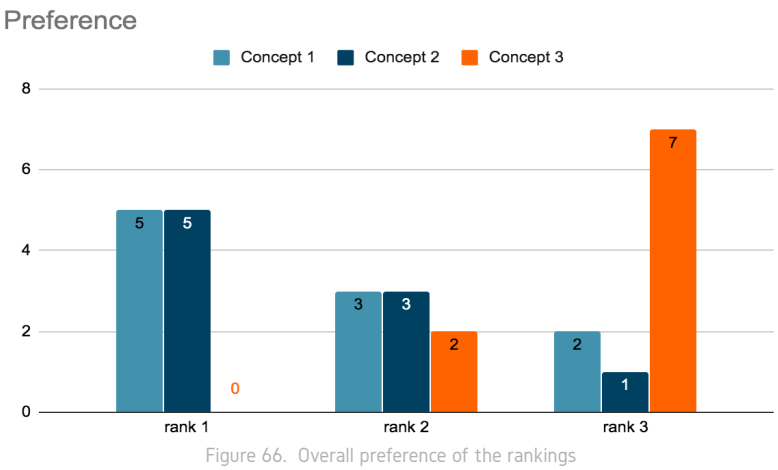


Figure 66. Overall preference of the rankings

Rank the three concepts

From figure 57, we can see the numbers of participants who have chosen concept 1 or concept 2 as their favorite are the same. Concept 3 is the least preferred.

4.3.2.2 Comparing between the Chinese and Dutch participants

Apart from similar feedbacks, there are some, there are some obvious differences between the two groups. We are going to find the differences between these two groups from two aspects: 1) their different comments on each step; 2) comparing their overall impression on these concepts.

Interactive elements

Before using the product (S1), when considering the trustworthy (Figure 67), Group 1 (+1) gave a much higher score than Group 2 (-0.6) for Concept 1. The score for Concept 3, Group 1 (+0.6) is much lower than Group 2 (+1.8). The difference in Concept 2 is not very obvious.

As for the effortless(Figure 68), the two groups have different attitudes on Concept 2. The main reason is that Group 1 (+1.8) indicates that they are familiar with using the app. But Group 2 (+0.2) gave a low point for studying the voice guide before use. For concept 1 and 3, the differences are not very obvious.

During the early stage of use (S2-S6), the difference from the score of trustworthy is also on Concept 2. The evaluation given by Group 1 on steps 5 and 6 is relatively high because they are familiar with the use of mobile apps. The low evaluation of Group 2 is due to the distrust of voice interaction and not particularly fond of the app.

As for the effortless, Group 2 (0) shows a negative attitude towards Concept 2 on step 4 (canceling an incidental cleaning), since neither do they want to use voice control to input their instruction, nor the mobile app.

For the long term of use, there is no difference in preference between the two groups in both trustworthy and effortless. Although two groups think concept 3 is not effortless, Group 1 (-0.8) gave a lower score than group 2 (+0.4).

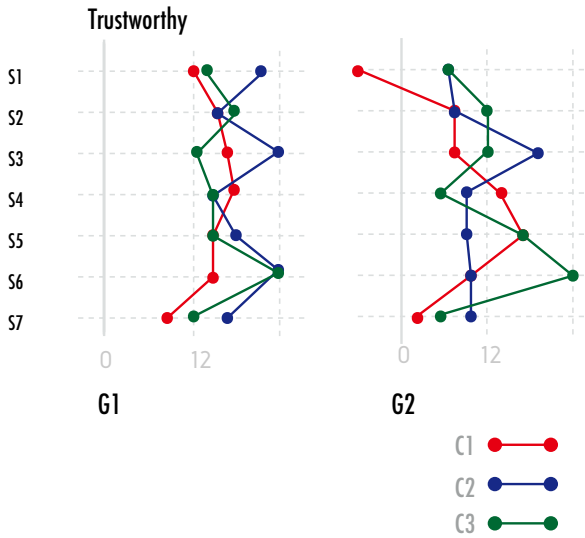


Figure 67. The score of trustworthy

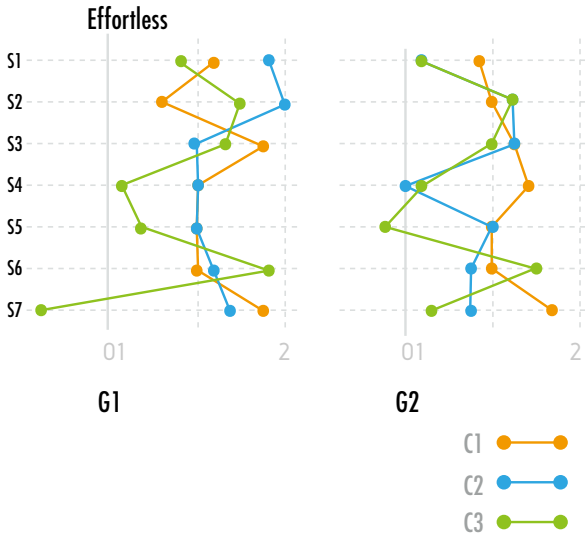


Figure 68. The score of effortless

Overall impression

Group 1's overall impressions of Concept 2 on trustworthy and effortless are higher than the other two concepts. Group 2 thinks Concept 3 is the most trustworthy but Concept 1 is the most effortless.

When choosing their favorite concept, the two groups have a lower preference for Concept 3, while having no significant difference in Concept 1 and 2. (Figure 69)

Although The high intelligent product (Concept 1) is acceptable for both groups, Group 1 is willing to imagine a fancier performance, while Group 2 will consider more about the reliability of the product. A participant in Group 1 mentioned that "I'm considering if it is an individual product or part of the smart home. For instance, if it can be connected with a smart shower or smart-tap, then it doesn't need to study the user's behavior but to use data from other smart devices to reason what you are doing. In China, it is a trend to have a smart home. I have my Xiaomi smart speaker and use it quite often." Participants in Group 2 asked many questions about the intelligence, "How long does it take to learn my pattern? If it takes one month or longer, why not set it manually at the beginning?" Also, one participant in Group 2 said she was not interested in the smart home things; connecting wifi before using a device was too much for her and made her feel unsafe.

The comments on choosing Concept 2 are also different. Participants from Group 1 are familiar with using mobile apps and voice control to operate smart devices. Group 2 think mobile apps are more reliable to set up or monitor complex tasks. A participant in Group 1 said, "I will go everywhere with my cell phone, even to the toilet." Another participant also mentioned that "I am used to using mobile apps to handle all kinds of daily things." The participants in the second group said that "You can check all the things whenever you want." Also "the operations I did on my cell phone are more thoroughly considered."

Summary

One thing that needs to be stressed is that the number of participants in this test is not enough to draw a quantitative conclusion for the whole Chinese and Dutch young adults. We only point out the obvious differences and insights found in this study.

In general, the overall decisions made by the two groups on the interaction concept are basically the same, but the reasons behind it and the related considerations are different. The main findings are as follows:

Similarities

- Both groups like the highest intelligence in concept (C1) and show little interest in the most traditional concept (C3).
- Both groups would like to interact with the intelligent device in a more controllable way.
- The mobile app is the most promising interaction technique for showing complex information about this device.

Differences

- Chinese users may have more imaginations about the intelligence of products, while Dutch users are more rational about intelligence and more concerned about its achievability.
- Although the two groups did not have a positive attitude towards voice interaction in this interaction, the Dutch had a lower rating than the Chinese.

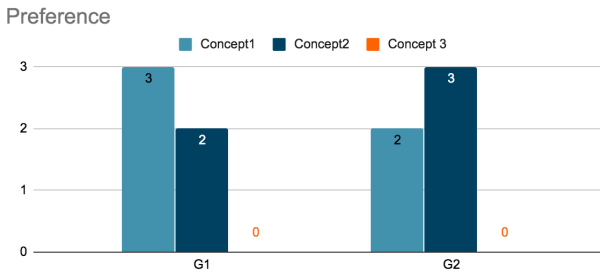


Figure 69. Best prefered concept of the two groups

4.3.4 Conclusion

After analyzing all the findings, **Concept 1** was the most promising concept for both groups. The reasons are as follows:

- From the perspective of intelligence level, the participants like the most intelligent concept. The participants have a high expectation of it before use and agree that this concept is promising to offer an effortless solution for bathroom floor cleaning in the long term.
- From the perspective of the interaction technique, the touchscreen on the wall can offer a trade-off for the context of the bathroom. Since the bathroom is a functional place, most of the users will think about bathroom cleaning only when they approach it. The touchscreen on the door of the bathroom is easy to reach.
- From the perspective of emotional expectations, since the users do not need to worry about the bathroom cleaning in the long term, it is the most effortless concept.

However, there are some interaction elements in Concept 1 that can be improved:

- The facial recognition function can be removed. The participants do not understand the usage of it. After being explained, they think it is not necessary to have a too personal cleaning service.
- The mobile app can be used as a supplement for showing detailed information.
- Since users will not stay in front of the bathroom door for a long time, they do not have time to see more detailed cleaning reports. However, without knowing detailed cleaning information, the trust towards the product will decrease. From the findings from Concept 2 and 3, we found that users tend to view complex information and make important decisions with their mobile phones. Consequently, we can use the mobile app as a supplement for the touchscreen to show detailed information, and to increase the sense of trust.
- Signal lights can be added on the device for noticing the condition of the self-cleaning system.
- The signal the garbage disposal (blinking icon on the screen) is easy to be ignored. For this interaction, the user has a high rating for Concept 3 (signal lights on the device). Therefore, we can add signal lights on the device to indicate the usage status of the self-cleaning system.

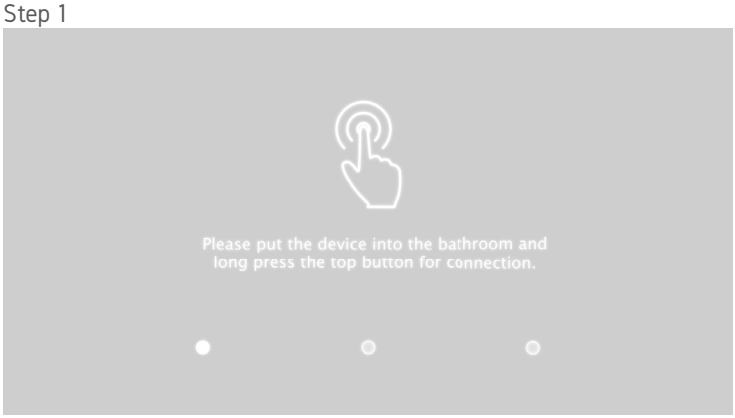
4.3.5 Final interaction concept

Following the conclusion above, the device concept with the highest intelligence level in Concept 1 was chosen as the final interaction concept. The touch screen is still used as the interaction technique for timely monitoring and manual adjusting, while the facial recognition part was removed. The mobile app (interaction technique in Concept 2) is added as a supplement for showing detailed information, such as a detailed cleaning history. Since the previous interaction that using a blinking icon for notification is not obvious enough, we change the color to red which is much more attractive (interaction element in Concept 3).

The main task flows and interfaces of the final interaction concept are shown in the following pages.

INSTALL THE INTERACTION DEVICE

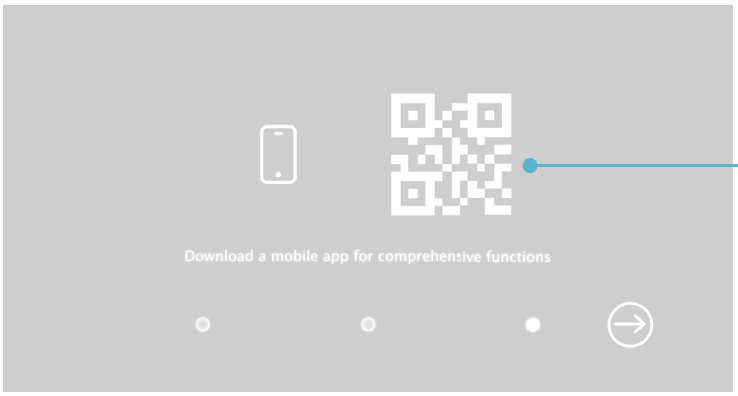
Step 1

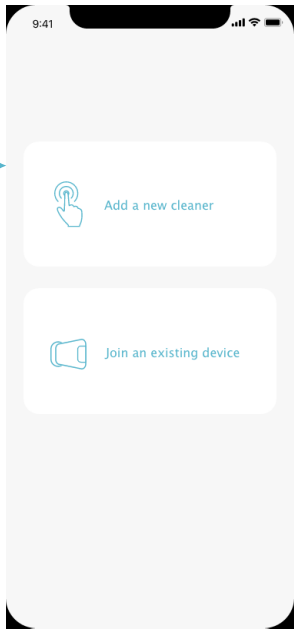


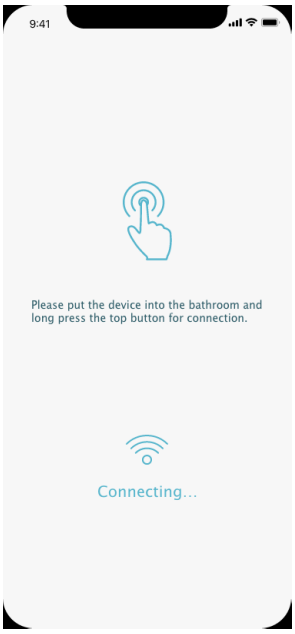
Three steps:
1. connect the device and the touchscreen
2. install the device at the outside of the bathroom door.
3. download a mobile app (optional)

Step 2

Step 3

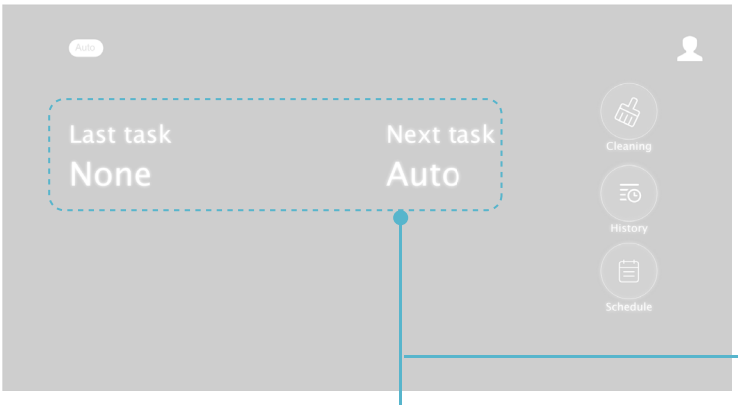


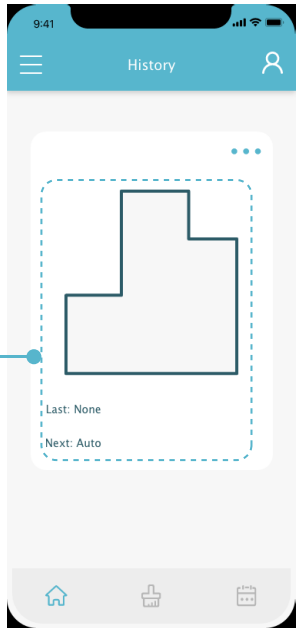




(Installed)

BEFORE USE

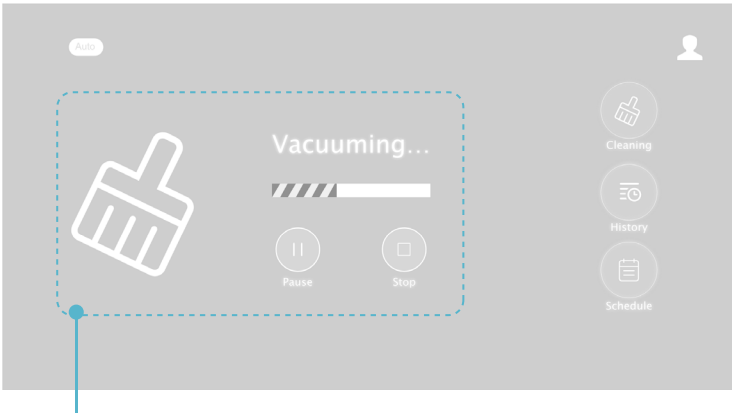


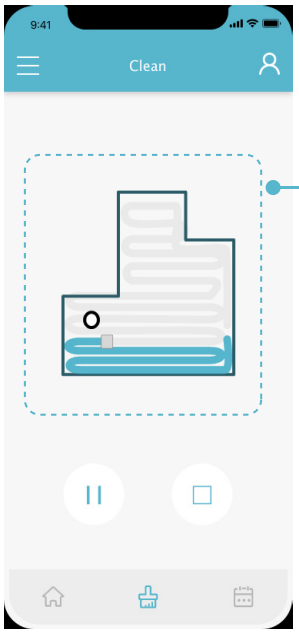


NOTIFICATION (LAST/NEXT CLEANING)

The cleaning type and time of the last and next cleaning. If no scheduled task recently, next task will be shown as 'auto'.

DURING AN INCIDENTAL CLEANING (EARLY STAGE)





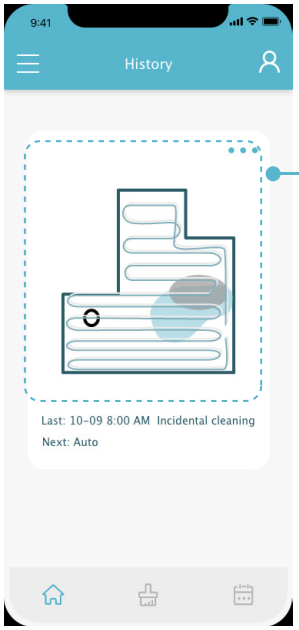
NOTIFICATION (CURRENT CLEANING)

Using obvious icon to show the current cleaning tasks. The progress bar shows the expected cleaning process. User can pause/stop/restart the task.

NOTIFICATION (CURRENT CLEANING)

Showing a predicted cleaning route and the cleaning process. Different colors are used to distinguish different tasks.

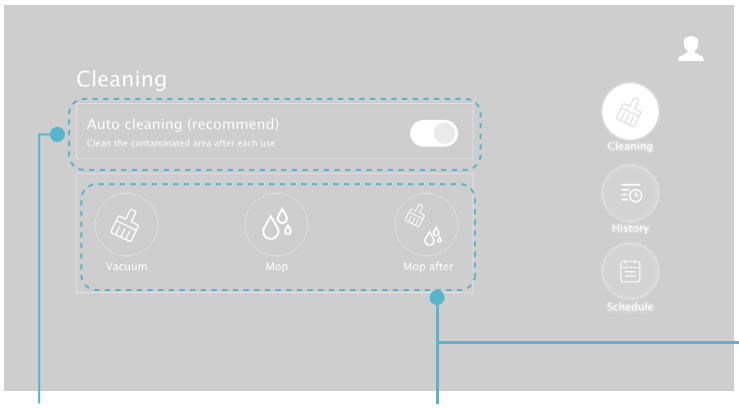
AFTER A CLEANING

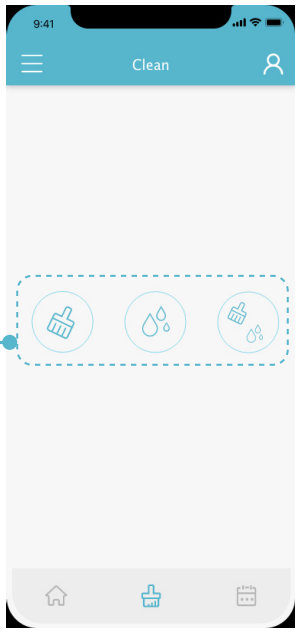


DETAILED INFO (LAST CLEANING)

A detailed cleaning route and the dirty place the robots detected during the last cleaning will be shown.

MANUALLY START





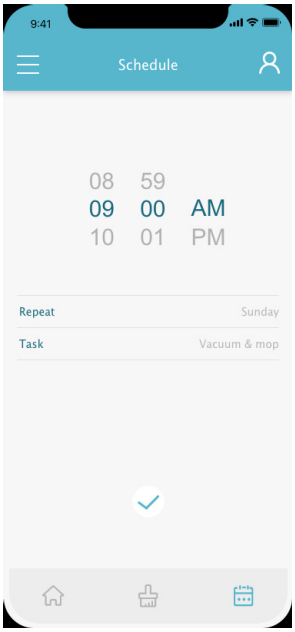
AUTOMATIC MODE

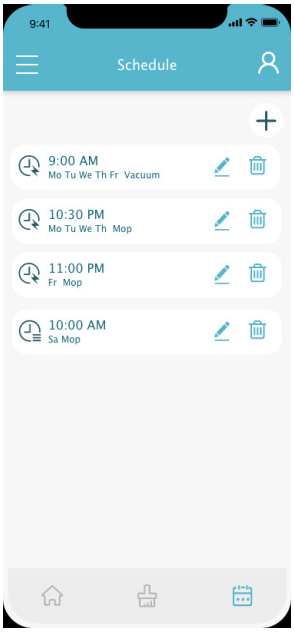
The incidental cleaning mode is on by default.

MANUAL CLEANING

Three cleaning types can be chosen:
1. vacuum only
2. mop only
3. mop after vacuum.

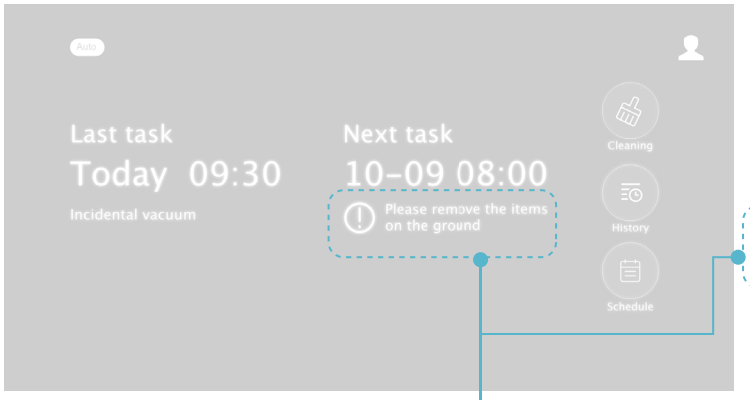
SET A SCHEDULED CLEANING

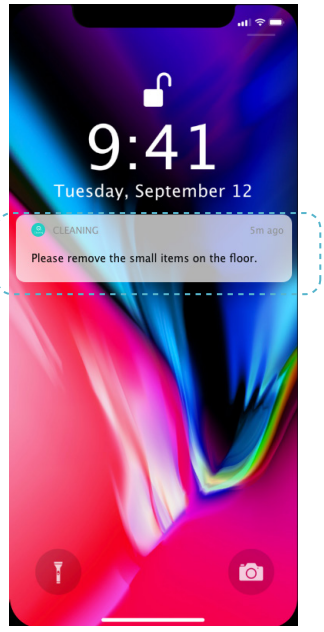




Manually set a scheduled cleaning task by choosing time, robot type and repetition mode by touchscreen or mobile app. The app will show a detailed scheduled lish while the touchscreen will not.

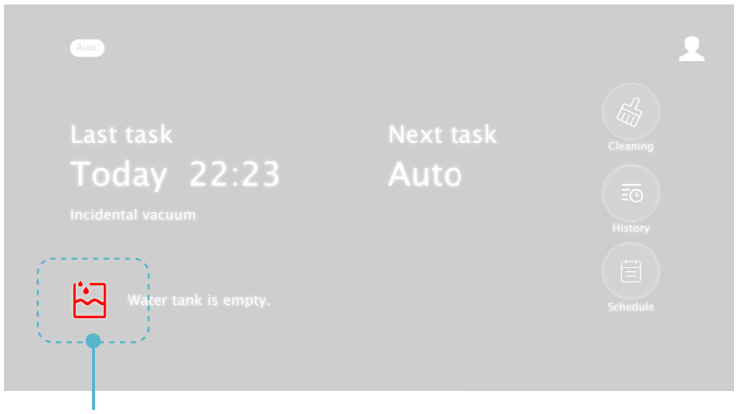
BEFORE A SCHEDULED CLEANING





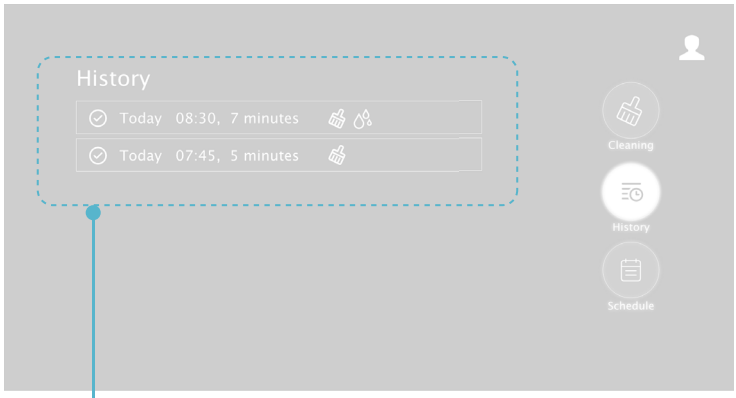
One day before a scheduled cleaning, the blinking icon on the touchscreen will inform the user to remove the movable items on the floor. The notification will also appear on the mobile phone.

GARBAGE DISPOSAL / EMERGENCE RESPONSE

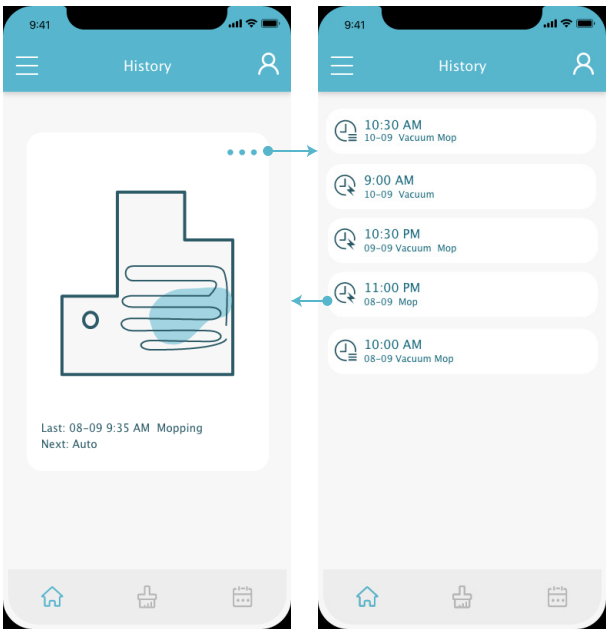


Red blinking icon on the touchscreen to inform the user the important information.

CLEANING HISTORY



Apart from the simplified cleaning task info on the default screen, a list of the recent cleaing tasks can also be quickly check through 'history' page.



Through the mobile app, a detailed cleaning history can be check. The user can see the cleaning route and the dirty place of each task. With the increase of the intelligence, the route matches the dirty place better and better.

4.4 FINAL CONCEPT EVALUATION

4.4.1 Objective

Currently, the final interaction concept has been identified. However, we have not evaluated whether the overall solution can meet the design goals, and is there any improvement needed. The aim of this section is to evaluate the final concept to explore its actual impact, and then, to find opportunities in the current design and prepare for the final recommendation.

4.4.2 Approach

Preparations

- A concept animation that demonstrates the expected user experience. (Figure 70)
- Application mockups simulate the touchscreen and mobile app.

Participants

Since the final device and interaction prototypes are not fully developed, it might be difficult for some people to imagine the experience of using this product. Therefore, we invited 4 IDE students who have experience in smart product design, in order to get more credible results.

Research questions

- To what extent do the participants feel the design meet the goal of creating a trustworthy and effortless bathroom cleaning experience?
- How do the interaction elements work in the concept?
- Are the participants willing to buy it in real life?

Procedure

We did an evaluation session with four IDE students. First, the background and the aim of the project were introduced. Then, a concept animation was made to tell the whole user experience of using this product to clean the bathroom floor. After that, the interaction prototypes created in Adobe XD were

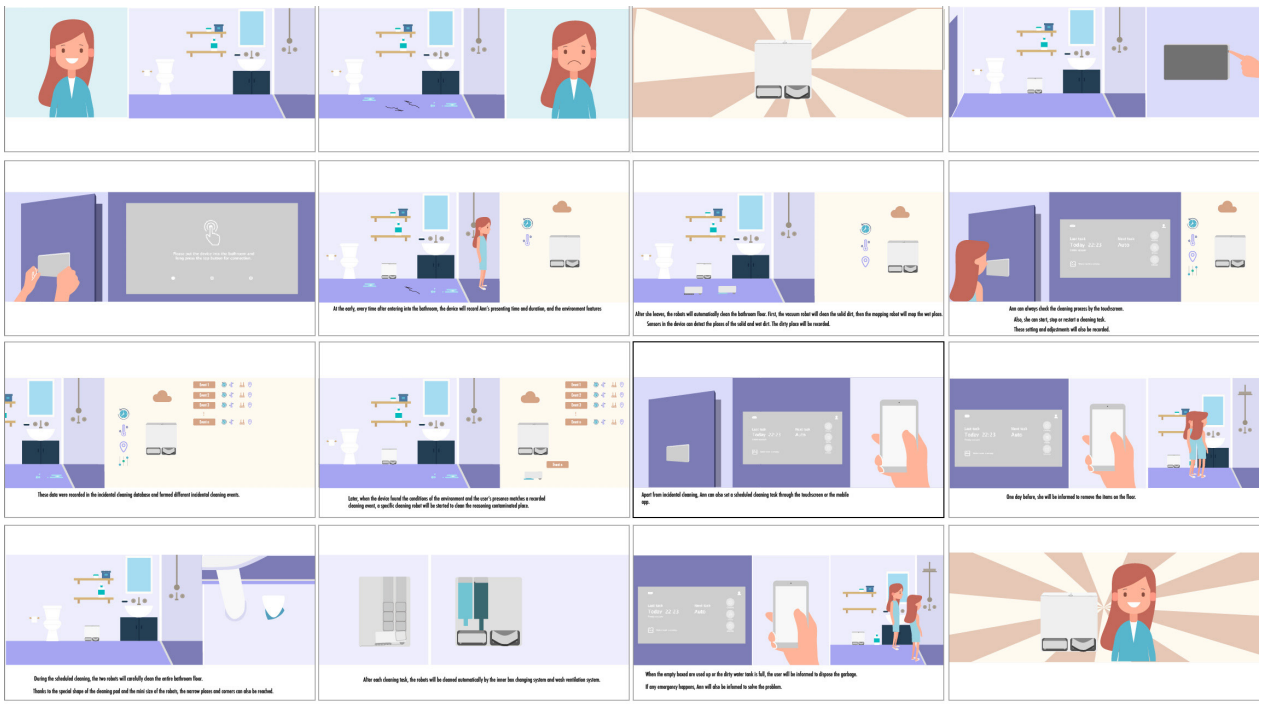


Figure 70. Screen shots of the concept animation

used to introduce every feature of the concept. The touchscreen part was shown on a laptop, while the mobile app part was shown on a mobile phone (Figure 71). The participants were able to comment or ask questions during the process. After that, they were interviewed to ask feedbacks and suggestions.

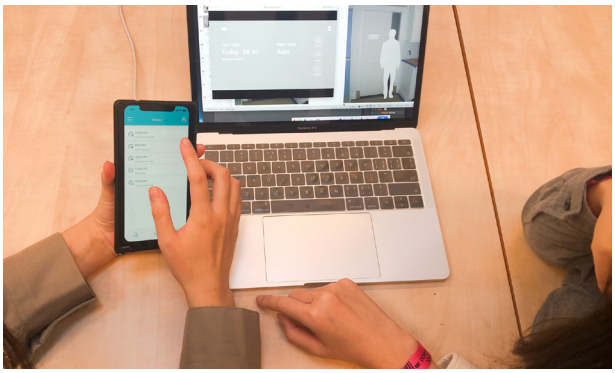


Figure 71. The prototypes for the evaluation session

4.4.3 Findings

4.4.3.1 To what extent do the participants feel the design meet the goal of creating a trustworthy and effortless bathroom cleaning experience?

Effortless:

In general, it is effortless to use the device to clean the bathroom floor. Participants emphasized that the incidental cleaning task made them feel relaxed. The operations that required people to participate (such as changing water) are acceptable and do not increase any extra burden.

However, the participants in the session found the following problems on the information display, which make the interaction troublesome and take extra effort.

P1 Showing unnecessary information. At first, participants could not quickly understand the meaning of the path on the mobile app. After the explanation, they thought that the information could be obtained directly by observing the cleanliness of the floor. This information adds no value but confuses the participants.

P2 The meaning of some information is indirect. For instance, we use the text 'auto' to represent the next incidental cleaning. However, different participants had different understandings of this text. It takes time for them to learn the meaning of this information.

P3 The information on the touchscreen and the mobile app are not clearly differentiated. The expected role of the touchscreen is to show timely information, while the app is for displaying complex information. However, the participants could not distinguish the type of information, which leads to the fact that they did not know which interactive technology to use.

Quotes:

"The incidental cleaning is automatic, which is effortless. If the five points are the highest score, I will give four points."

"It gives me too much information. Also, the information, such as the cleaning route, is too raw. I don't need that. After cleaning, I can directly see the cleanliness of the bathroom. The cleaning route is unimportant for me."

"The form of the state is only text. Maybe it takes some time to learn the meaning. For example, I don't know what the 'auto' under the next task means. Is it better to use icons?"

"Are the information on the touchscreen and the app the same or not? How can I know what the screen can do and what the mobile app can do?"

Trustworthy:

The trustworthy of the concepts consists of two parts: the ability to deal with contaminants and the ability to speculate on cleaning tasks. During the session, the participants did not question the cleaning ability of the device concept, but had a lot of confusion on the function of reasoning the incidental cleaning. Trust may increase with the effectiveness of machine learning, but current designs do not intuitively show the results of the learning process. Specifically speaking, the information about the last cleaning route and the contaminated place on the mobile app only shows a single task, but users cannot see if the machine is learning, or if its cleaning route becomes more accurate.

Quotes:

"I don't want it to be totally automatic. I can't trust the device to do everything. Maybe because it is my bathroom, I want to feel that everything is in control. "

"Trust may increase if it knows how to clean and clean better than me. It can have a learning process. When I find it becomes trustworthy after a while, I will let it go."

"I can't feel its progress or changes through the current interaction. The cleaning path is only about the one cleaning task, rather than a learning result. Maybe a report is needed. After its machine learning, it can tell me how it makes progress or the summary of my habits or routines. Maybe I can get some useful information through the report."

4.4.3.2 How well do the interaction elements work in the concept?

Preparation

The interaction functions during preparation are easy to understand and execute. Participants mentioned that there may be some problems in the actual operation, such as Bluetooth matching problem. But this is not the main point of discussion of the project.

Incidental cleaning

If the device could properly clean the dirty place, the interaction here was trustworthy and has no problem, and participants would not take the initiative to see detailed cleaning information. They said they would check the cleaning path only when the contaminants were not totally cleaned. However, since neither the touchscreen nor the APP cannot manually select the cleaning area, the participants felt that the interaction with the machine was very passive. They recommended that users need more initiative.

Scheduled cleaning

The participants liked the function of noticing on moving small items one day before the cleaning because they will have enough time to prepare. However, it was mentioned that they might see the notification but did not want to move the items sometimes. We can indicate that users need advance notice of the device, but don't want to be forced by the device to do something.

Notification on the cleaning tasks

For the touchscreen, the last cleaning task is clear and direct. However, the information on the next incidental cleaning is not clear. The meaning of 'auto' is not informative and beyond the user's control. Since the touch screen is also a place for showing the result of the machine learning, the participants recommended replacing the text 'auto' by specific task information.

Notification on the garbage disposal and others

The participant could notice and understand these notifications, but they had problems with the frequency of garbage cleaning. The self-cleaning system in the base station decreases the frequency of the manually cleaning, but at the same time, increases the risk of the garbage being wormy. Besides, users want to be able to control the time of disposing of the garbage, rather than being notified when the trash can or water tank is full.

4.4.3.3 Are the participants willing to buy it in real life?

Since the lack of market knowledge, we cannot give a specific price for this smart bathroom floor cleaner. The discussion on this issue is freer. During the session, the participants put forward a question about the using place of this product. Since the bathroom is small, they would not buy expensive sweeping robots for this single room. Therefore, they hoped that the product can also be used in other places besides the bathroom.

4.4.4 Conclusions

The design goal put forward in 2.4.3-Design goal shows that the concept is expected to achieve three levels of requirements. The results of the final concept will be discussed based on the two levels.

The first level: Clean the bathroom floor.

- Fit with the environmental conditions
- Cover all the cleaning related concerns

The cleaning device (the base station and two cleaning robots) are designed following the environmental requirements carefully. Thus, it can be run in the bathroom environment. The interaction parts (touchscreen and mobile app) are not using in the bathroom, so they do not need to meet these requirements. To sum up, the whole concept can fit with environmental conditions. For the cleaning related concerns (in 2.1.4-Context aspect conclusion), the requirements are also met. To sum up, the final device and interaction concept is able to clean the bathroom floor and reach the first level of the design goal.

The second level: Have a trustworthy and effortless experience.

- trust the work of the product.
- save time and effort

The participants cannot build sufficient trust with the device through the interaction concept. We found during the test that the trust in the product is based on the ability to clean the contaminants and the accuracy of the prediction for incidental cleaning. Because of time and technology limitations, we cannot build a workable prototype to test the ability to clean the contaminants. Thus, the focus is supposed to be how to transfer the intelligence, which means the accuracy of the prediction for incidental cleaning, to the user. However, the evaluation shows that participants cannot trust the intelligence of the device directly through the interaction. Specifically speaking, the user cannot see the improving process of the cleaning path planning or specific prediction for the next incidental cleaning. Through Figure 72 we can see the difference between the current interaction flow and expected one. Therefore, building a trustworthy experience through the interaction concept in this project still has a lot of room to improve.

As for effortless, the participants also verified during the evaluations that the chosen device concept has a relatively high level of intelligence and there are not many operations that need to be done by the user compared with the traditional bathroom cleaning. Therefore, it is safe to say that the design can save time and effort. However, some of the details of the interaction still need to be improved to make the operation more effortless, such as the information display can be improved (detailed problems can be found in 4.4.3.1).

In general, the envisioned product is promising to clean the bathroom floor, and offering users an effortless bathroom floor cleaning experience. However, trust in the product is still lacking.

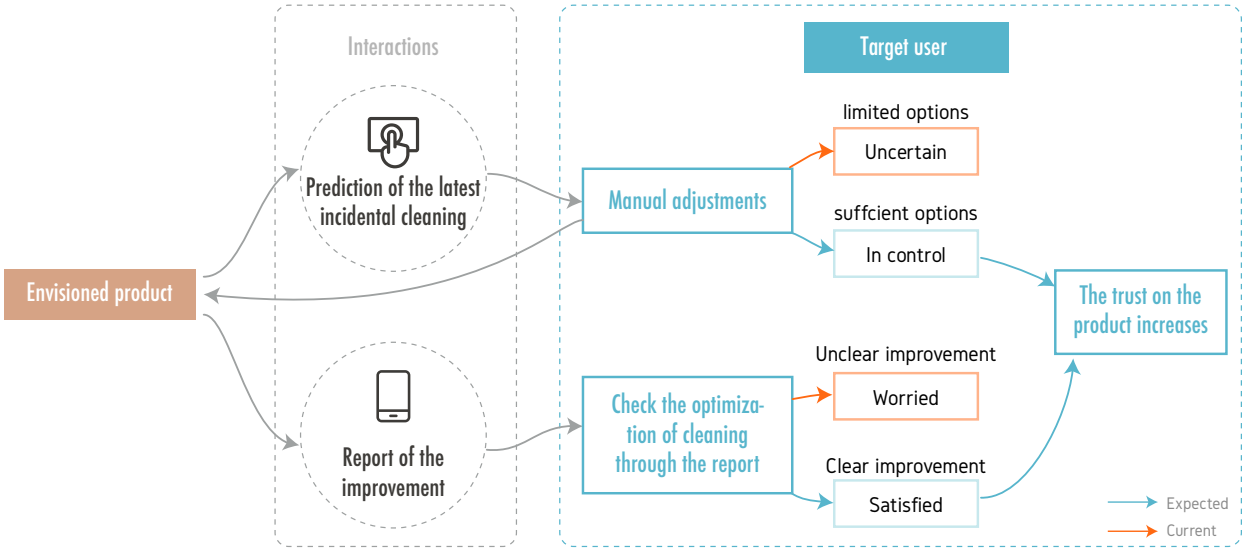


Figure 72. The interaction flow: current vs. expected

4.4.5 Limitations

4.4.5.1 Limitations of the prototype

Because of time and technology limitations, the evaluated prototype has many limitations, which lead to the risk of the result. The following shows two main risks.

First, the device prototype does not have a real cleaning ability. The first level of the design goal on the envisioned product is a good cleaning ability. However, the introduction of the device concept is based on CAD pictures and verbal descriptions, which is unable to prove the actual cleaning ability of the device. Therefore, the feedback from the users is partly based on their imagination, which makes the evaluation result has risk.

Secondly, the impact of long term use is hard to estimate. The intelligent increase of the device requires a certain amount of information collection. However, we cannot imitate long term changes due to time and technology limitations. During the evaluation sessions, we were inquired several times that 'How long is the time for machine learning?' It is safe to say that the time and result of the machine learning influence the design a lot. Although at the last evaluation, we invited design students who are more experienced with the smart product design who might imagine the long term use result more easily, this risk still cannot be ignored.

4.4.5.2 Limitation of the participants

The limited number of participants cannot represent the whole target group. The participants have different interests in the smart device, which is not about their nationalities but more about personal habits. Although in 2.xx and 2.xx, we found that the character of the Dutch target group shows less interest in smart devices, the opinions of limited participants cannot represent two cultural groups. A representative example is that one of the Dutch participants said that he was very interested in smart products and liked to play with high-tech. Thus, the low number of participants cannot be used to draw a quantitative conclusion on the cultural difference analysis.

4.4.5.3 Limitation about the market issue

In this project, the evaluation of the market is lacking. We did not calculate the cost and pricing of the envisioned product because of the limited time and knowledge. However, it is obvious that the device concepts with different intelligence levels will have different prices. During the evaluation sessions, some of the participants asked the price of each concepts and said they prefer the cheapest one. This indicates that the price will influence their choices. Therefore, different costs and pricing may lead to a different result.

5. RECOMMENDATIONS

5.1 PROJECT IMPROVEMENT

5.1.1 Analysis

In the context analysis part, the following two points can be improved: 1) The participant's number (51) is not large enough to draw a quantitative conclusion. The analysis of the indirect context concluded that Chinese and Dutch participants do not show significant differences in bathroom usage and cleaning habit. However, some delicate shades of the differences might be missed because of the lack of the participants. 2) Researches on the user's attitudes towards smart products need to be deeper. The current researches are mainly about bathroom usage and cleaning but lack research on users and smart products, which leads to a lack of design in terms of increased trust in the Conceptualization phase.

The technology aspect contains two parts. The first is to find suitable structures and technologies. Most of the smart products and technologies are studied from the existing smart cleaning products, without considering more cutting-edge or conceptual products. If new technologies have chances to be applied, we need further study. The second is about Cyber-physical systems. CPSs are new but fertile domains. Plenty of knowledge can be studies. In this project, we only applied the most appropriate principles that we can find in a limited time. But other principles may be better at developing this project.

As for the business aspect, we only analyzed a narrow perspective of the smart home product market and general consumer behavior. The cost and approximate pricing of the product are not considered. This is because this project mainly focuses on the intelligence of the device. In the evaluation stage, we did not mention the difference in the cost of each concept, which made the participants more focus on intelligent differences. However, since the envisioned product will be a consumer good, we recommend having a more comprehensive study on the business aspect.

5.1.2 Conceptualization

For the device concept development, the limited is caused by the lack of knowledge about the product design and software logic process. Most of the information is gathering from academic resources, website researches, and conversations with experts. We did not validate the trusted functionality of the device concept. However, since the device structure will influence the interaction, the device concept of equipment needs to be more realistic but not too conceptual. To improve this, we recommend cocreating with experts to further develop the device concept and to make it more reliable.

For the interaction concept developments, the places for improvements are mainly these two parts: 1) the performance of the different levels of intelligence, 2) the lack of resources to gain inspiration for detailing the concepts.

The interaction concepts are based on device concepts in different intelligent levels. The difference in intelligence in this project mostly focuses on incidental cleaning. This is because incidental cleaning is one of the main bathroom cleaning concerns. However, there are also other concerns (e.g. scheduled cleaning) need to be discussed.

The inspirations for detailing the interaction concepts are quickly gained from mood boards. which is too limited. The elements obtained may not be rich enough and the interaction concept should be further refined. To improve this, more creative conceptualization methods can be used.

5.1.3 Evaluation

The main weaknesses in the evaluation part are can be found in XXX-limitations. The followings are recommendations for these limitations. For the limitation of the market issue, it has been discussed in 5.1.1-analysis recommendations.

1. Prototypes

The first limitation is the form of demonstration prototypes. Due to the time limitation, we did not make physical models to demonstrate the concepts but used visual and text to explain the device concepts. If more time were given, a detailed and physical mockup can be built to simulate the envisioned product. The second is stimulation in the long term of use. It will be better if the participants are more expert on smart product design, or if time is possible, to have a real long-term experiment to get more accurate conclusions.

2. Participants

The limitations of the participants are their attitude towards smart products and the insufficient number of participants. It is necessary to inquire about their attitude towards smart products before the evaluation. Participants with greater tolerance and innovation will be more welcome to do the evaluation. As for the number of participants, it is impossible to draw significant comments about the difference between the two cultural groups. In order to get a statistical conclusion, more participants are needed.
Further development opportunities are found throughout the whole design process. The first is about the application of CPSs principles, which is the main approach for developing the project. The second is to improve the device concept which currently has a negative impact on the interaction. After that, interaction design opportunities can be further developed to finalize a comprehensive system. Please note that CPSs principle application development is only based on subjective feelings with insufficient academic researches, so we cannot guarantee that all the opportunities have the same academic research significance.

5.2 FURTHER DEVELOPMENT

5.2.1 CPSs principles and interaction design

CPSs is a new domain, which means there are not many mature methods that can be directly applied to interaction design. Based on personal experience, I found this opportunity that can be developed further: Application of different CPSs principles in different design stages. For instance, we used CPSs implement technologies and principle of event-oriented control during the development of the physical device, while used intelligence levels for developing interaction concepts. However, in the practical process, many other principles have also been tried as approaches in different stages, which took a lot of time but without good results. If the principles can be given some specific application areas, or they can be summarized as specific design methods, interaction design for CPSs will be more specific methods, and the interactive design approach can be further supplemented.

5.2.2 Self-cleaning function improvement

After the evaluation, the physical device function which is the most needed to be improved is the self-cleaning function. The reasons are as follows:

1) This is the only one that must be done manually, which makes the interaction less effortless. What's more, the user cannot proactively choose the time to clean. This also leads to negative feedback. The problem is caused by the physical structure of the self-cleaning system. For the box-changing system, the dirty boxed cannot be removed until all the dust boxes are filled. For the wash and ventilation system, although the user can clean the water at any time, they cannot directly observe the tank capacity.

2) The frequency of the disposing of garbage decreases, but the chance of garbage becoming wormy increases. The current self-cleaning system does not have a sterilization function. However, considering the special environment features of the bathroom, we recommend that if the self-cleaning system prolongs the time of garbage storage, the sterilization function needs to be taken into account.

5.2.3 Interaction design of domestic smart products

There are two opportunities related to interaction design that summarized from the sessions. The first is how to build trust between the user and the smart products. Although the trustworthy requirements come from the bathroom context research and mainly related to cleaning functions, later we found that participants' evaluation of trust is influenced by the functions related to the intelligence. However, the current interaction makes the intelligence of the product looks like a black box. The user cannot truth the smart device through the current interaction. Therefore, how to establish trust between users and smart products is a place worth studying.

The second is how to integrate a new smart product to the current context. In this project, there are two separated interaction devices, namely the touchscreen and the mobile app. However, the participants mentioned that they already have a smart speaker

or other smart home devices. They hope this smart bathroom cleaner can be integrated into the current smart home system, so there is no extra effort to install the device for interaction or to learn a brand new interaction. Therefore, it is interesting to analyze how to integrate the interaction of the envisioned product into the current context.

5.3 PERSONAL REFLECTION

Research phase

General design methods:

At the beginning of the research, I tried to use context mapping to gain insights of the deeper needs. Since a context mapping session takes too much time, I could only find four participants who had time to join. The results from a limited number of participants cannot be used to draw any significant result. But later, I used the insights of the context mapping (together with website researches) to generate a questionnaire. Since questionnaire research has no time or place limit, I got a lot of responses from the target group in a short time. This makes me learned that it is necessary to consider the time required before the research and the difficulty of finding suitable participants. Besides, even if the number of participants is not enough, available results can be found in the data obtained.

CPSs design methods:

It takes plenty of time to choose suitable CPSs principles during the design process. At first, I was not familiar with CPSs knowledge and did not know how to apply it to the project. Although my tutor gave me a lot of guidance, I did not have a deeper understanding of these guidelines until the second half of the project. To sum up, as far as I am concerned, the expert's guidance is very helpful for me to study new knowledge, while learning in actual cases can make me better understand it.

Dealing with project complexity

Define the main contradiction

At first, the predicted contradiction between the Chinese and Dutch is their bathroom using and cleaning habits, and the target user is defined as Chinese and Dutch young adults who share a bathroom with others. During the research phase, I found there were several contradictions related to this definition: 1) the requirements of bathroom cleanliness vary from person to person, 2) the relationship between the roommates influence their requirements on bathroom cleaning, 3) the Chinese and Dutch target groups have different level of acceptability on smart bathroom products. At first, I tried to balance all the contradictions in one design, which made the early concepts very complex but without a clear aim. After some hard trade-offs, I chose the third contradiction as the design point because it is closest to the context of CPSs, and then removed the 'house sharing' conditions in the target group definition in order to weaken the other two contradiction. This decision gave the following process a clear goal, and made the final result more targeted. This makes me realize that it is very difficult to solve all problems at once. A better approach is to divide the complex problem into small ones and solve the most important ones first.

Time planning

In general, the time planning before the midterm is appropriate, but the time after is a little bit mass. After the midterm, I realized the time pressure and therefore began to design the interaction concepts without defining a clear and feasible device concept. Although the work took a lot of time, the results were unsatisfactory and useless. Under the guidance of the supervisors, I redo the conceptualization phase and refine the design results. These took plenty of time, but finally, I made some nice progress. As a warning for the future, it is important to do one thing step by step at one time. A hasty acceleration will only waste more time.

In general, this project is very valuable and significant for me because I not only had a chance to use all skills that I learned during the last two years but also learned a new way of thinking, namely smart system thinking.

REFERENCES

1. Horváth, I., & Wang, J. (2015, August). Towards a comprehensive theory of multi-aspect interaction with cyber physical systems. In ASME 2015 International Design Engineering Technical Conferences and Computers and Information in Engineering Conference (pp. V01BT02A009-V01BT02A009). American Society of Mechanical Engineers.

2. Leichsenring, C., Yang, J., Hammerschmidt, J., & Hermann, T. (2016, November). Challenges for smart environments in bathroom contexts. In Proceedings of the 1st workshop on embodied interaction with smart environments (p. 3). ACM.

3. Slávik, M., & Centre, A. R. (2014). Hygrothermal loads of building components in bathroom of dwellings. Advanced Materials Research Vol. 1041 (2014) pp 269-272.

4. China Institute of Building Standard Design & Research Co., Ltd. 14J914-2 Domestic Bathroom. Beijing, China; 2016.

5. Ministerie van binnenlandse zaken en koninkrijksrelaties. Handreiking Bouwbesluit & woning. 2015.

6. Bathroom Flooring Guide. Armstrong Flooring Residential. [cited 2019 23-04-2019]; Available from: https://www.armstrongflooring.com/residential/en-us/inspiration/bathroom-flooring-guide.html.

7. Best Flooring for Bathrooms. The Spruce. [cited 2019 23-04-2019]; Available from: https://www.thespruce.com/top-bathroom-flooring-options-1821353.

8. Qiu, W. (2010, January). The Comparative Study for the Bath Culture and Appliances Development between China and Europe.

9. De geschiedenis van badkamer. Affaire d'Eau. [cited 2019 28-04-2019]; Available from: https://www.affairedeau.com/nl/service/badkamergeschiedenis/

10. pwc, Smart home, seamless life: Unlocking a culture of convenience. Consumer Intelligence Series, 2017. [cited 2019 30-04-2019]; Avaliable form: https://www.pwc.com/us/en/industry/entertainment-media/publications/consumer-intelligence-series/assets/pwc-consumer-intelligence-series-iot-connected-home.pdf

11. Technology - Altan Robotech. Altan Robotech. [cited 2019 30-04-2019]; Available from: https://altanrobotech.com/technology/.

12. Gordon, E. A. (1997). U.S. Patent No. 5,608,944. Washington, DC: U.S. Patent and Trademark Office.

13. Landry, G. W., Cohen, D. A., & Ozick, D. N. (2018). U.S. Patent No. 9,883,783. Washington, DC: U.S. Patent and Trademark Office.

14. Ramalingam, B., Veerajagadheswar, P., Ilyas, M., Elara, M. R., & Manimuthu, A. (2018). Vision-Based Dirt Detection and Adaptive Tiling Scheme for Selective Area Coverage. Journal of Sensors, 2018.

15. Park, J. H., & Park, D. R. (2011). U.S. Patent No. 7,920,941. Washington, DC: U.S. Patent and Trademark Office.

16. Fleming, M., Patrick, A., Gryskevicz, M., Masroor, N., Hassmer, L., Shimp, K., ... & Bearman, G. (2018). Deployment of a touchless ultraviolet light robot for terminal room disinfection: the importance of audit and feedback. American journal of infection control, 46(2), 241-243.

17. Horvath, I., & Gerritsen, B. H. (2012, May). Cyber-physical systems: Concepts, technologies and implementation principles. In Proceedings of TMCE (Vol. 1, pp. 7-11).

18. Horváth, I., Rusák, Z., & Li, Y. (2017, August). Order beyond chaos: Introducing the notion of generation to characterize the continuously evolving implementations of cyber-physical systems. In ASME 2017 International Design Engineering Technical Conferences and Computers and Information in Engineering Conference (pp. V001T02A015-V001T02A015). American Society of Mechanical Engineers.

19. Daudelin, J. (2018). Active Perception and Planning for Modular Self-Reconfigurable Robots.

20. The Chinese Institute of Electronics, CIE. Chinese Robotic Industry Development Report. Beijing, China; 2018.

21. GfK Consumer Life; Chinese consumer robotic industry. Beijing, China; 2018.

22. 36kr.com. [cited 2019 10-05-2019]; Available from: https://36kr.com/p/5160846. Published 2019. Accessed May 10, 2019.

23. Forward Business and Intelligence Co., Ltd., Chinese smart hardware development report . Shenzhen, China; 2018.

24. The Netherlands Foreign Investment Agency

(NFIA). Robotics In The Netherlands. Delft; 2016.

25. Nederlandse interesse voor Smart Home neemt af, ondanks stijgende bekendheid. Gfk.com. [cited 2019 10-05-2019]; Available from: https://www.gfk.com/nl/insights/press-release/nederlandse-interesse-voor-smart-home-neemt-af-ondanks-stijgende-bekendheid/. Published 2019. Accessed May 16, 2019.

26. Smart Technology: a simple and effective cleaning system. Toilitech. [cited 2019 10-05-2019]; Available from: http://www.toilitech.com/products/smart-technology/.

27. Reaching the Chinese consumer - Santandertrade.com. En.portal.santandertrade.com. https://en.portal.santandertrade.com/analyse-markets/china/reaching-the-consumers. Published 2018. Accessed May 19, 2019.

28. Accenture Consumers In The New China. Accenture; 2018. https://www.accenture.com/_acnmedia/pdf-81/accenture-capturing-growth-china-new-consumers.pdf.

29. Markets analyse-the Netherlands, Santander.com. [cited 2019 10-05-2019]; Retrieved from: https://en.portal.santandertrade.com/analyse-markets/netherlands/reaching-the-consumers?&actualiser_id_banque=oui&id_banque=0&memoriser_choix=memoriser

30. Harris profile - WikID, the Industrial Design Engineering wiki. Wikid.io.tudelft.nl. [cited 2019 10-05-2019]; Available from: http://wikid.io.tudelft.nl/WikID/index.php/Harris_profile. Published 2014. Accessed May 30, 2019.

31. Why You Only Need to Test with 5 Users. Nielsen Norman Group. [cited 2019 23-05-2019]; Available from: https://www.nngroup.com/articles/why-you-only-need-to-test-with-5-users/.

32. The Design Research – Sociotechnical aspects of Quality, Creativity and Innovation

33. Boeijen A, & Daalhuizen J (2010). Delft Design Guide. Delft: TU Delft.

34. Reuleaux triangle. En.wikipedia.org. [cited 2019 15-07-2019]; Available from: https://en.wikipedia.org/wiki/Reuleaux_triangle.

APPENDICES

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A. Context mapping

A.1 Objective

The aim of this research is to find:

- What is the bathroom usage and cleaning habits of Chinese and Dutch young adults?
- What are their expectations for bathroom floor cleaning?
- Is there any difference between their habits and expectations?

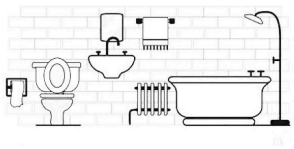
A.2 Approach

Four enquiry diaries (figure 1) have been sent to 2 Dutch students and 2 Chinese to record their daily bathroom usage time, their bathroom floor layout, and their time and methods of bathroom floor cleaning.

After they finished the diary, a session was held to discuss the bathroom usage and cleaning habits, their experience when cleaning the bathroom floor, and their ideal bathroom floor in the future (their expectations). Some generative toolkits were provided for inspiration (figure 2). The timetable for the session is in table 1.

Table 1. Timetable for context mapping session

time	action	checklist
5	Introduction	Goal: find how to improve the bathroom floor cleaning experience. (another aspect: culture difference) You are the expert, basic rules.
5	Warm-up	Every participant introduces themselves
10	Exercise 1: Make collage “the bathroom floor cleaning experience”	Using the words and images to describe your last bathroom floor cleaning experience. Where, who, when, what, seeing, feeling, smelling, hearing, mood...
15	Discuss	Explain it to others, you can react on each other’s story
10	Exercise 2: Draw ideal bathroom floor cleaner	Make a drawing to express your ideal bathroom floor cleaner in the future. You can also cut and glue the icons to express.
15	Discuss	Explain it to each other and react.
5	Closing comments	

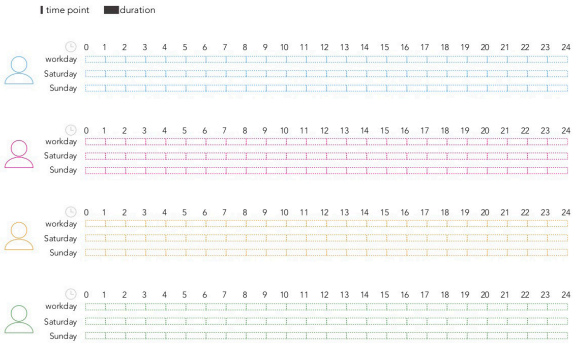


How do you use your bathroom everyday?
What will you do and how will you clean it?

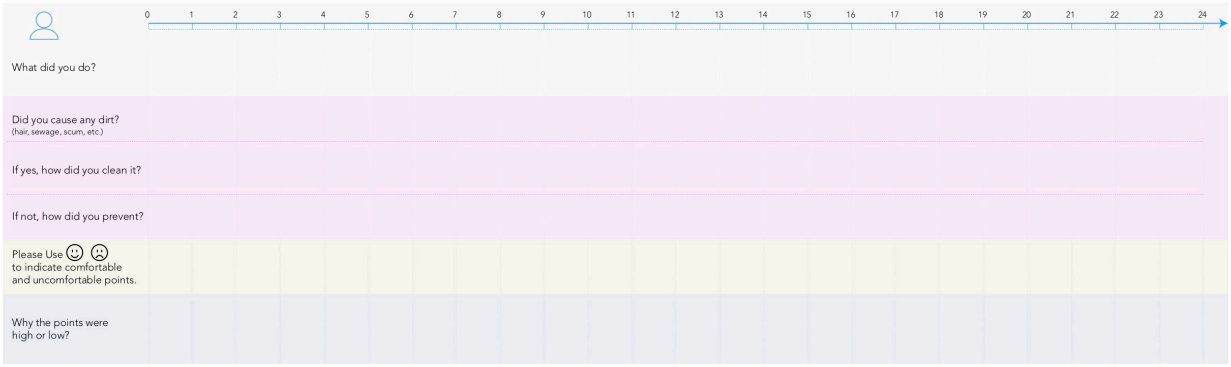
Please use this enquire diary to record your bathroom usage and cleaning habit.

You can stick it on the bathroom door for easier recording :)

1. When do you use bathroom and toilet **at home** during workdays/weekends? Please mark the first line of blank when using it. Do you have roommates? Please invite them to mark the other lines.



2. Please mark your workday again. Can you explain more about what you did and how you felt when using the bathroom? Please fill in the form below.



3. Please sketch the top view of your bathroom floor on the blank below. (the general layout, the objects or furniture on the floor, the flooring pattern, etc.)
If you have more than one, please draw all of them.

4. Do you periodically clean your bathroom? How did you clean it? Please fill in the form below. (If you do not clean the whole bathroom, please record how you clean the bathroom floor)

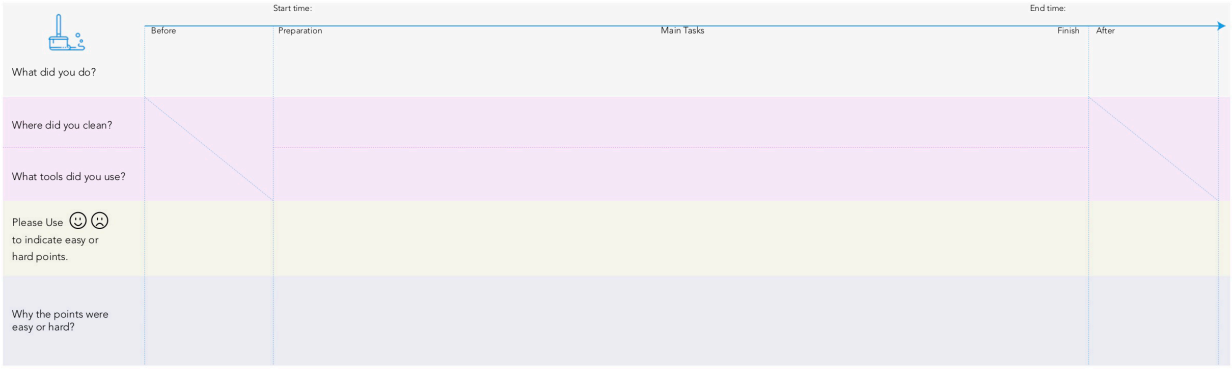


Figure 1. Context mapping enquire diary

Figure 2. Context mapping toolkit

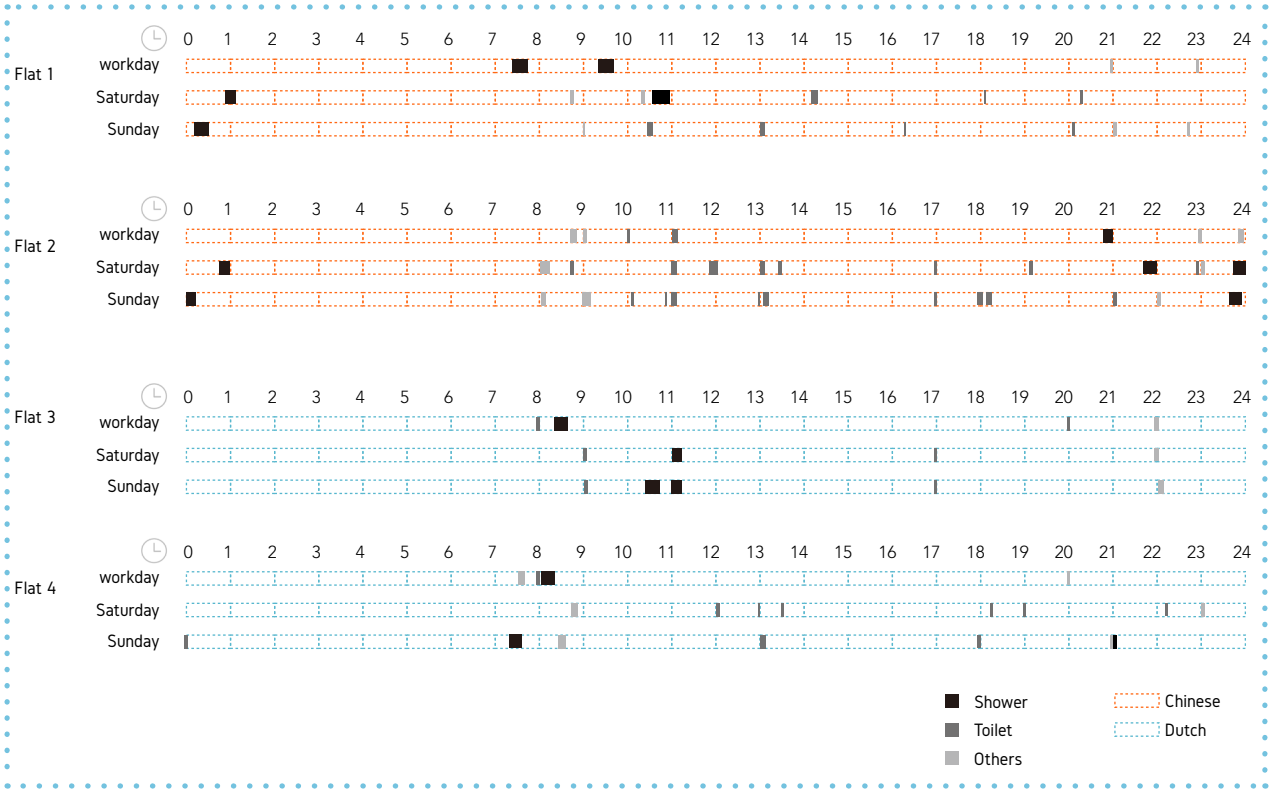


Figure 3. Bathroom usage time and duration

A.3 Results

It is important to note is that the results of the survey are usable only for gaining insights.

Figure 3 shows the bathroom usage time of Chinese and Dutch participants. It is important to note that the total number of Chinese and Dutch recorders are different, since the participants who received this enquiry diary had different number of roommates.

Things have done in the bathroom include showering, going to the toilet, brushing teeth, washing face, washing hands, shaving. However, the order of the tasks is a little different between: Chinese participants prefer to take a shower at night, while Dutch participants prefer in the morning. Hair is one of the major contaminants that both groups will clean during their daily usage. The participants will rinse away the hair on the floor after taking a shower.

The detailed results of exercise 1 and 2 are shown in figure 4 and 5.

Figure 4. Results of exercise 1

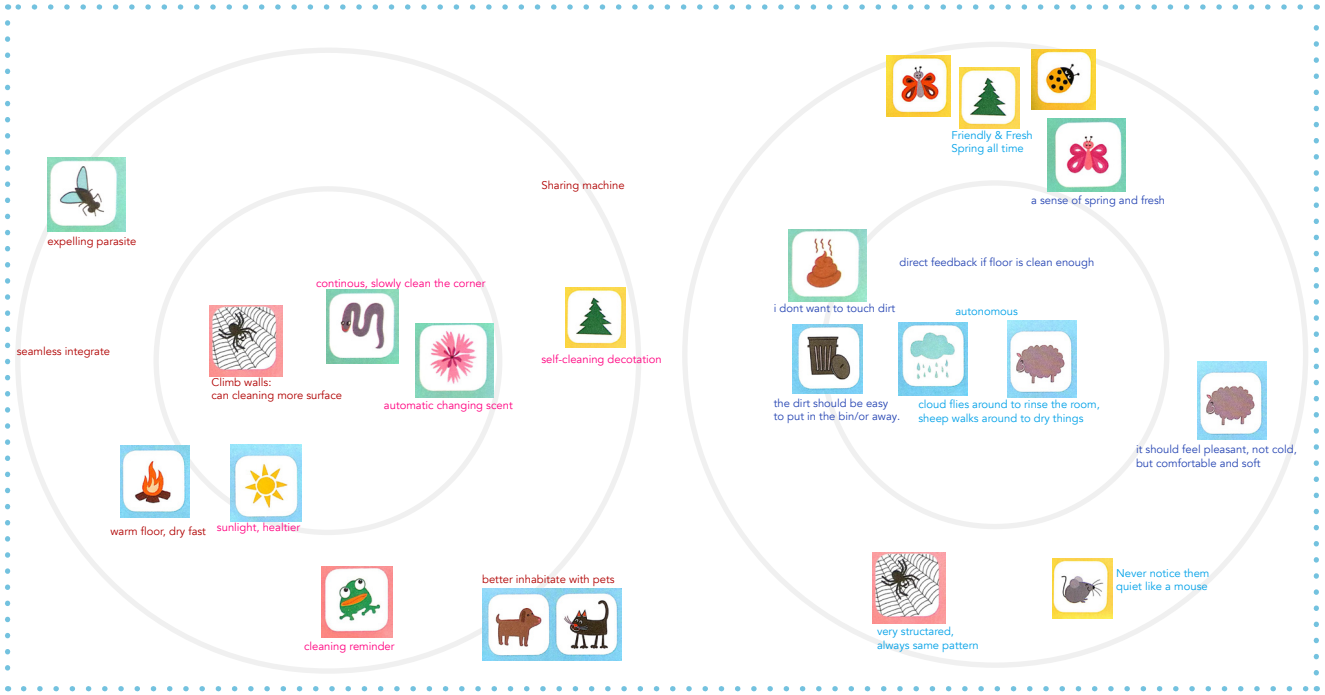


Figure 5. Results of exercise 2

B. QUESTIONNAIRE

B.1 Objective

- What is the bathroom usage and cleaning habits of Chinese and Dutch young adults?
- What are their expectations for the future bathroom usage and floor cleaning?
- Comparing the difference between their habits and expectations?

B.2 Approach

After the session, all the data were fixated and rearranged, in order to find pattern and create an overview. After analyzing the data, we found some differences between the Chinese and Dutch participants. In order to confirm these differences, a questionnaire has been sent to 20 Dutch and 31 Chinese young adults. The questionnaire has two versions: A Chinese version based on tencent online questionnaire which was sent to Chineses participants. A Dutch version based on google online questionnaire sent to Dutch participants. The only difference between the two versions is the language.
The following questions were asked:

1. When do you clean the collectively used bathroom? (After bathing / After using the toilet / After washing hands / Regular cleaning (daily, weekly, monthly, etc.) / When I find it is dirty)
2. What tools do you use to clean the bathroom floor? (Shower head to sprinkle water / Broom / Disposable wipes / Cleaning agents / Duster cloth / Brush / Mop)
3. Why do you choose this tool(s)? (It is convenient. / It is cheap. / It can clean quickly. / It can clean thoroughly.)
4. What is the most annoying when cleaning the bathroom floor? Please choose at most 3 options. (Move away the items on the floor / Clean the narrow places / Close to/touch dirt while cleaning / Monotonous work / Repetitive work / Throw away dirt after cleaning / Touch the cold and hard flooring)
5. Which floor condition do you prefer after cleaning? (Wet/dry) (figure 6-7)
6. What hi-tech bathroom related product do you use? (Smart floor cleaner / Illuminated mirror / Smart toilet / Smart shower / Smart bathtub / Smart faucet / Mobile app / None)
7. If you choose "Mobile App" in the last question, please provide the App's name.
8. If you choose "None" in the last question, please explain why you do not use smart in- bathroom products?
9. Which bathroom do you prefer? (figure 8-9)
10. Please write down a reason.
11. Which bathroom room do you prefer? (figure 10-11)
12. Please write down a reason.
13. What features do you like to add to your future bathroom cleaning product? (Self cleaning / Usage tracking / Bacteria detection / Thoroughly dirt cleaning / Personal health monitoring)
14. What benefit will trigger you to buy a smart bathroom related product? (Energy-saving / Security / Easy to use / Full-automatic / Self-cleaning / Playful / Water-saving / Healthy / Personalizing)
15. Any other comment?

Figure 6. "Wet floor is fine."

Figure 7. "I want it to dry as soon as possible."

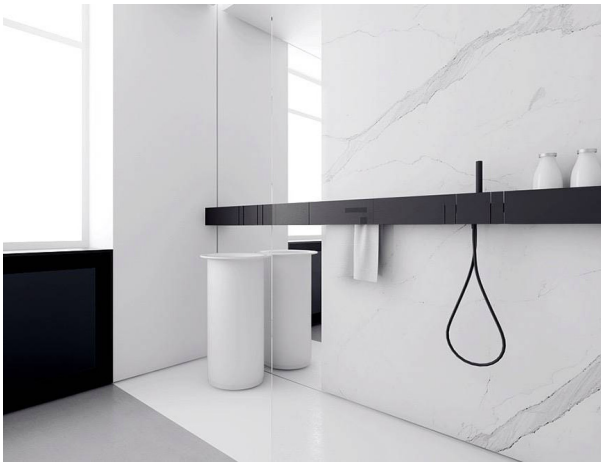


Figure 8. "With simple basic functions"

Figure 9. "With multiple playful functions"

Figure 10. "Natural with manual bathroom, cleaning, etc."

Figure 11. "High-technical with automatic monitoring, etc."

B.3 Results

Figure 12-18 show the results of the quetionnaire. The left charts of each question represent the Dutch participants' answers, the right charts are the Chinese participants'.

1. When do you clean the collectively used bathroom?

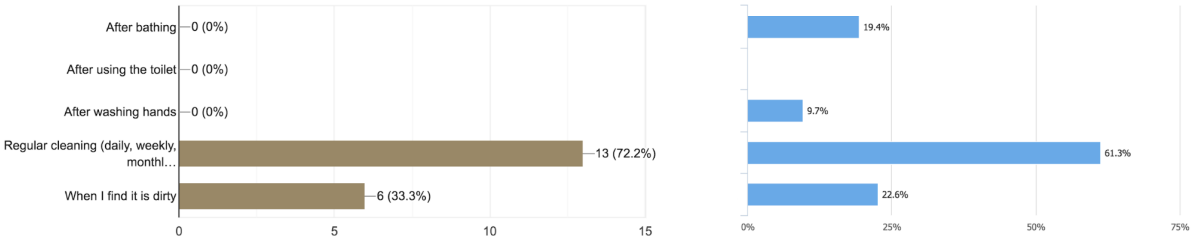


Figure 12. When to clean: Dutch vs Chinese

2. What tools do you use to clean the bathroom floor?

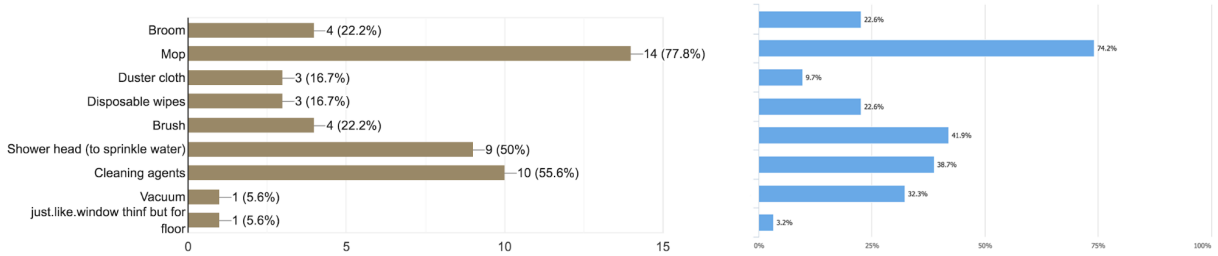


Figure 13. What tools to clean: Dutch vs Chinese

3. Why do you choose this tool(s)?

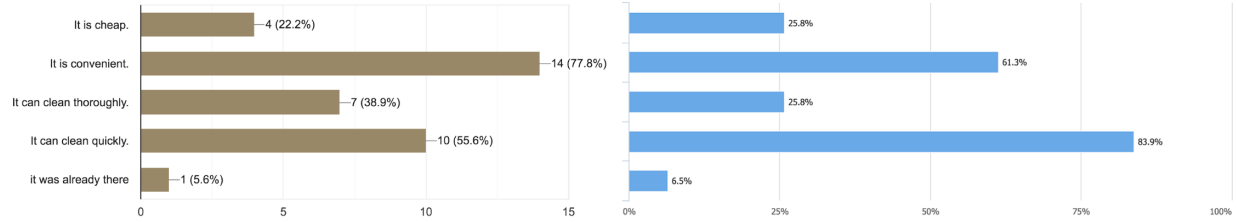


Figure 14. Why choose this tool: Dutch vs Chinese

4. What is the most annoying when cleaning the bathroom floor?

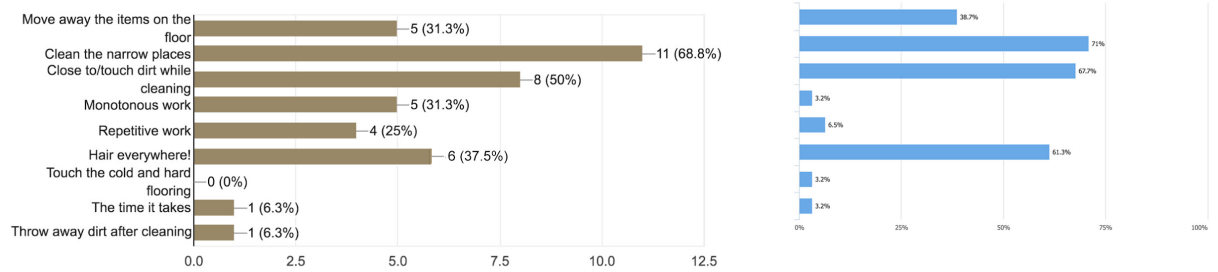


Figure 15. What is the most annoying thing: Dutch vs Chinese

5. Which floor condition do you prefer after cleaning?

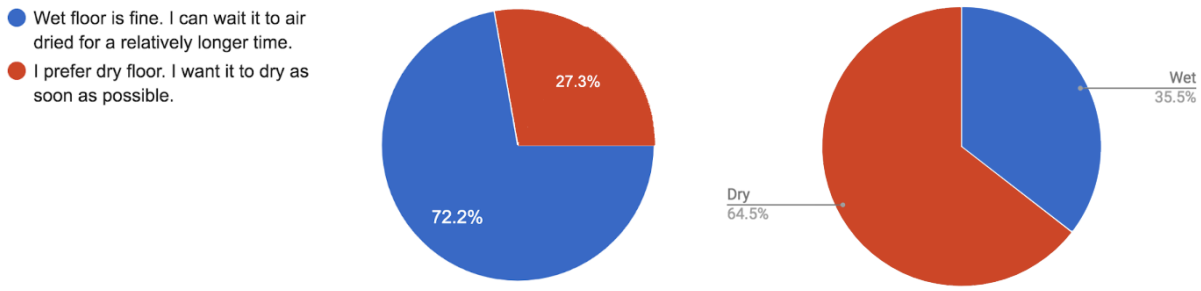


Figure 16. Wet/dry floor: Dutch vs Chinese

6. What hi-tech bathroom related product do you use?

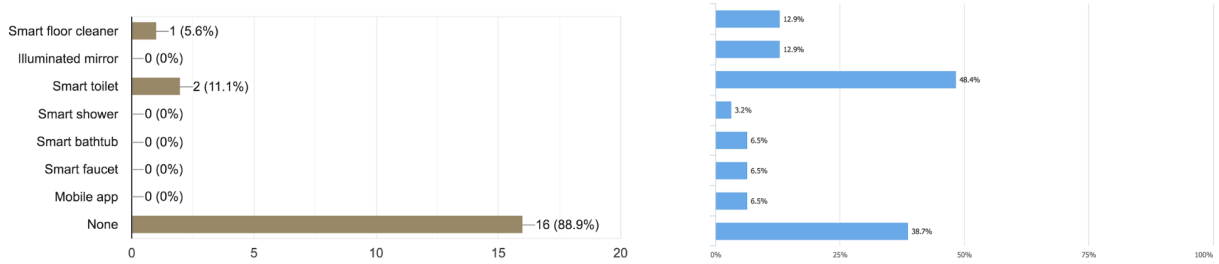


Figure 17. Hi-tech products: Dutch vs Chinese

8. (If choose none in the last question) Why don't you use it?

DUTCH
expensive. *5
Too expensive and not that necessary.
I dont know what it is.
We were not used to do that. There seems no need to use that.
we live in an old house and i think we don't need it.
Old fashioned, never taught about connecting my bathroom to the internet of things.
we don't have the money and it would break or stop functioning in our housing environment.
High Tech features do not fit our student budget and I don't see the need for it.
not needed. the standard products work fine.
never considered it.
I have simply never purchased one.
Expensive, Will probably break Anyway in Student homes, since IT get easily neglected.

CHINESE
Poor *7
It is unnecessary *2
Never thought about using smart products.
Did not learn about it.
Didn't buy it
Clean the bathroom manually, do not need any instrument.

9. Which bathroom do you prefer? (simple/playful)

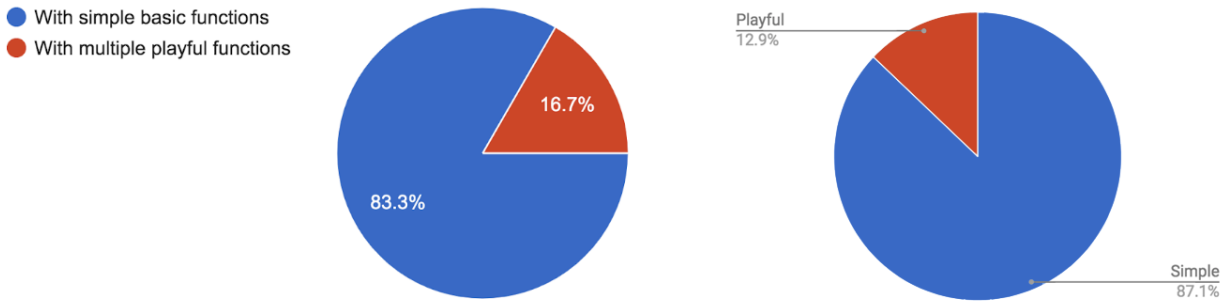


Figure 18. Simple/playful bathroom: Dutch vs Chinese

10. Please write an answer.

(For participants who chose simple bathroom)

DUTCH
Easy to clean *2, I do not spend that much time in a bathroom
I like clean simple spa vibe
looks clean *2
Playful functions belong to the kitchen or living room
Showering takes enough of my time, i don't have time for more in the morning
I like a minimalistic design.
It should just be functional
i dont spend more time in the bathroom than necessary
i like.simplicity and less distractions.
im there to get clean, use the toilet nothing elsep
I want to come to rest when i am washing myself, especially after a long day

CHINESE
Playful things are better to have in certain place. Bathroom
Entertainment projects are better to be done in proprietary locations. The bathroom is a place for convenient bathing.
Won't stay in the bathroom if have nothing to do.
Looks very clean. *2
Bathroom does not require entertainment.
Like simple style.
Don't want to spend too much time in the bathroom.
less is more.
Just want to take a shower. *2
I don't need that versatility, the bathroom is the bathroom. *3
I don't live in the bathroom, I want it to be so versatile.
Don't like that complicated.
My request is not high.
Functionally.
looks good.
efficient.
Looking comfortable.
personal habit
Clean and simple
Comfortable and not messy
No money.
Convenient.
Worried that it is not clean or unsafe.
It's not too long to stay in the bathroom, entertainment is not necessary.

(For participants who chose playful bathroom)

DUTCH
Because cleaning yourself is boring.

CHINESE
It looks interesting! But not sure if I will feel boring later.
Relax and creative.
Cozy
Like listening to music and watch videos when taking a bath.

11. Which bathroom do you prefer? (natural/high-tech)

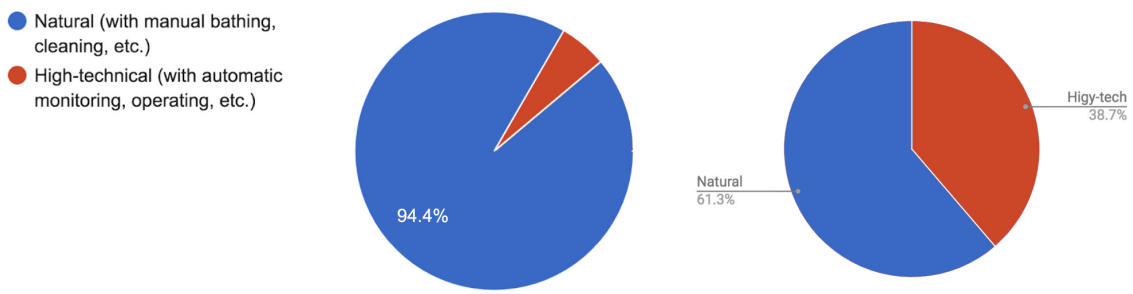


Figure 18. Simple/playful bathroom: Dutch vs Chinese

12. Please write down an answer.

(For participants who chose natural bathroom)

DUTCH
Relaxing, me time.
Not necessary.
nutral materials.
I want to keep it simple and cosy.
it.feels a bit.warmer.
Because being close to nature makes me feel more fresh.
Gives me more a sense of peace and quiet.
zen
Old fashioned.
It has more feeling to it, the high tech feels cold.
i dont like the unnecessary luxury.
I don't see the need for High tech features.
i like less distractions.
i would not like to be monitored on the toilet.
More simpel, like the bright and natural aesthetics.

CHINESE
Used to it *2
Technology is not all-pervading yet, and i don't trust it.
I like to be more comfortable at home.
Just take a shower
Technology is too fragile
A place to relax *2
clean
Low cost
Do it yourself and know what you need
Technology is a bit ugly
Warm
Look more comfortable
More natural and comfortable
personal habit
Relax, there is some intelligence
No money at home

(For participants who chose hi-tech bathroom)

DUTCH
I like to play with technology.

CHINESE
Convenient *5
Lazy *3
More smart
Lazy, but the manual one looks good.
More comfortable
Who don't like smart things?
simplify matters.

13. What features do you like to add to your future bathroom cleaning product?

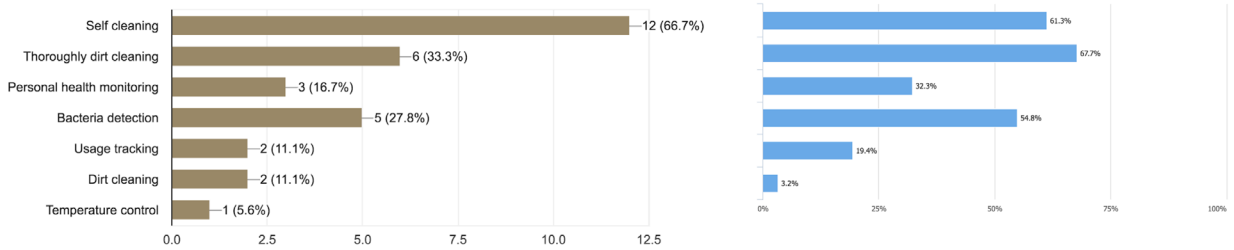


Figure 19. Desired features: Dutch vs Chinese

14. What benefit will trigger you to buy a smart bathroom related product?

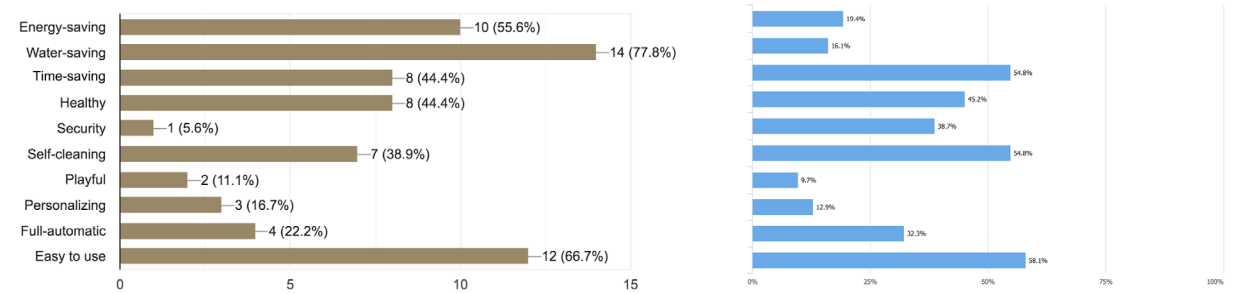


Figure 20. Trigger of buying smart products: Dutch vs Chinese

C. Value towards cleanliness

C.1 Objective

The final objective of this smart cleaner is to provide a clean bathroom floor for the target users. However, the meaning of bathroom cleanliness is different from person to person. In this part, we asked 8 target users based on a collage of pictures about clean, in order to gather some inspirations of how they think about domestic bathroom cleanliness. Since the number of participants is not enough to provide a quantitative solution, the results will only be used for inspiration, and to support the later researches.

C.2 Approach

Research questions:

- RQ1 Is it possible for a shared bathroom to be considered as a clean place?
- RQ2 Does disposable object means clean to them?
- RQ3 Do different states of water (static, flowing, liquid, gas, etc.) affect the feeling of cleanliness?
- RQ4 Will the smell affect the feeling of cleanliness?

Methods:

Different pictures (figure 21) that can represent the cleanliness in the research questions were carefully chosen. Then, a collage formed by these pictures was shown to 8 target users to ask their understanding of cleanliness and bathroom cleanliness.

The questions are:

1. Which picture do you think is clean? Why?
2. When it comes to domestic bathroom, which one or which part of the pictures will make you feel clean? Why?

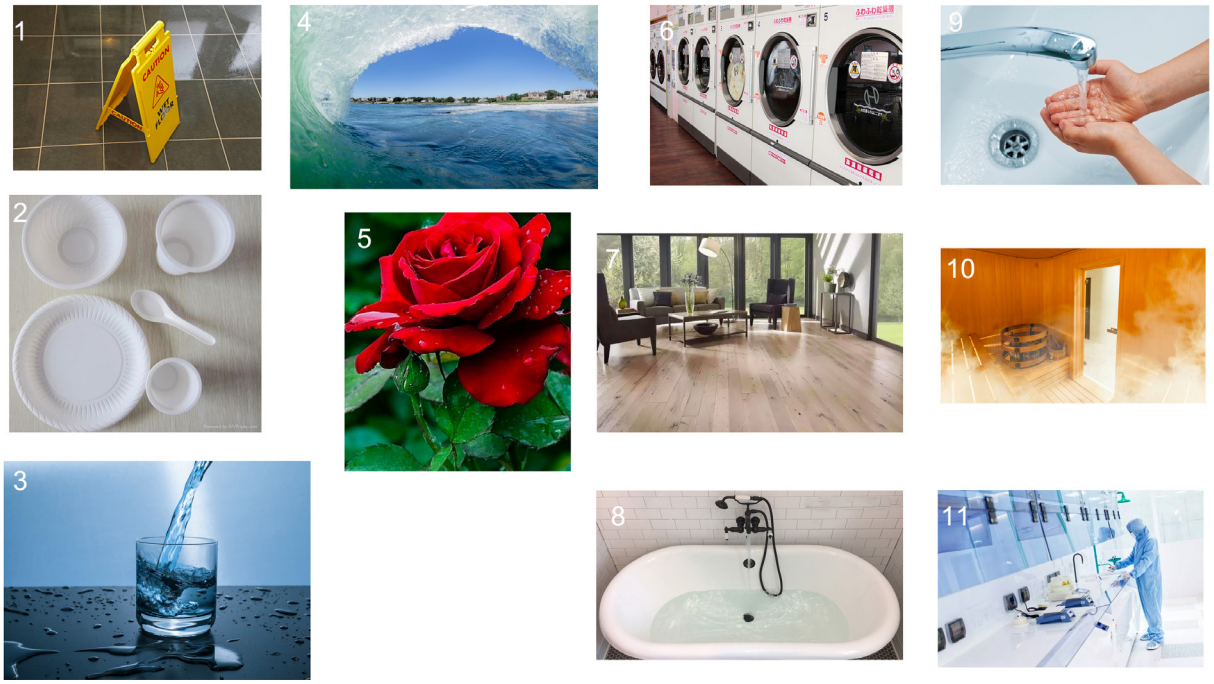


Figure 21. Trigger of buying smart products: Dutch vs Chinese

C.3 Reesults

Dutch participant 1:

Answer 1: 7, 9, 11
Answer 2: 8, 9

- 1 reminds me of clean in a bathroom situation, but not domestically. It reminds me a public bathroom which are usually not that clean.
- 3 is clean but it's like a photo shot rather than a real situation.
- 4 I wouldn't say it is clean but after a long day at the beach you will still shower or something. You will still wash off after interacting with these things or in this situation.
- I didn't really consider the wetness or dryness. Although 7 looks very dry of course, you don't see any trash or dust, but washed things will literally remind me of cleanliness.

Dutch participant 2:

A1: 6, 9

- 9 I think the shining things in the bathroom reminds me of clean.
- The wet or dry doesn't matter.
- I live with a lot of people, so a shared laundry room doesn't matter. I think it is clean.
- The ocean or the flowers will don't remind me of clean. The smell also doesn't matter.

Dutch participant 3:

A1: 3, 4, 9
A2: 1, 8, 9

- Clean means a lot, for me, like 1) washing myself clean. 2) is a definition of clean environments, like there is no trash. 3) something like clean water.
- I didn't choose 1 because something it is wet doesn't mean it is clean. Some people don't clean properly. sometimes they just wet the floor to wet the floor, but they don't clean it properly. Sometimes it is not clean but just doing a cleaning task.
- 2 is not clean. For me it is trash, it is plastic, you use it and then throw it away, and makes the environment dirty.
- 4 is pure but not clean. 7 is a clean apartment but not associated with clean.
- 8 I never take a bath to clean myself, I take a shower. Bath is like relaxation.
- My bathroom is the only place that I wet my floor of my apartment.
- Smell of rose doesn't have anything to do with cleanness. it is lavender or citrus that might have this effect. I don't think smell have much things to do with cleanness.
- 7 is more like tidy/clean. I think clean is more like anti-bacteria, also no dirt.
- Actually, I don't use a public washing machine, because people come and go. For me it is not a personally association.

Dutch participant 4:

A1: 2, 3, 7, 9, 11
A2: 1, 3, 8, 9

- 10 is like a public washing place, and I don't really go there.
- 4 is beautiful picture, but nature is not always clean. For example, the water in the ocean is not always clean. The water looks clean, but you don't know what is in it. That's also why I choose tap water.
- 5, rains drop on the flower, there are always something small things, some sand in it, which is not clean.
- When it comes to bathroom clean, I will not immediately think of smell.
- 2 is like a new product. There are always clean when you get them out.

Chinese participant 1:

A1: 2, 4, 5, 7,11
A2: 2, 4, 5, 7

- 1, The public environments which you need to share with many other people will made me feel dirty. If the place just belongs to me, then it feels clean.
- 2, I don't really care about the quality, but the thing should belong to me, I am the first one who use it.
- In 10, the damp and wet hideouts might contain lots of dirt that you cannot see, which makes me feel dirty.
- 3, the place with water makes me feel dirty. I like dry floor (7).
- 4, 5, a sense of blue, fresh, fragrant bathroom makes me feel clean.
- 11 is too clean for domestic bathroom, and the smell makes me nervous.

Chinese participant 2:

A1: 2, 7, 9

- I choose 2, 7 because I like the warm and dry wood floor. It makes me feel clean. (2, 7)
- I didn't think about the smell when you mentioned clean.
- In 3, 4, 8, you don't know what is in the water, so I didn't choose.

Chinese participant 3:
A1: 3, 5
A2: 9

- 3 is a cup of purified water, of course it is clean.
- 5 the fresh flower and rain makes me feel fresh, it is a kind of clean nature.
- The clean and flowing water... and that you are washing hands, which means you are cleaning yourself.

Chinese participant 4:
A1: 2, 6, 7, 9, 11
A2: 3, 6, 10, 11

- Color and material influence my choices a lot. I like the white color of the disposable tableware and the blue color of the glass cup, which reminds me of clean. Also, the wood and glass material look very clean.
- The dry wood floor looks clean. But I will not choose it as bathroom floor, because it will be very easy to corrupt in the wet environment.
- It might be abnormal that I really like the smell of disinfectant fluid. I know many people don't like it, but I like it. If my bathroom has this smell, it makes me feel it is clean.

C.4 Insights

I1 A shared space that has been cleaned does not mean it is clean. People may think about whether the cleaning tool is clean or if it has been cleaned properly.
I2 A shared space has possibility to be regarded as a clean place, especially for the people who has used to live with others.
I3 When considering the actual situation of the nature, the participants did not think it is clean. However, the feeling of fresh that the nature brings may let them feel clean.
I4 The disposable object represents different meanings. Some participants regarded it as a personal item or the first-time item, which means it is clean. However, it is not clean from the environment friendly perspective.
I5 We could not find a clear connection between the state of water and clean from this research. The washed floor may literally mean clean, but the dry floor was also preferred by several participants.
I6 The smell does not have a clear influence on the participants' awareness of cleanliness.

D. Early device concepts test

For integrating the element ideas into three device concepts, we used a poster based presentation to explain the physical functions of each concept. Then, the participants need to fill in the preference questionnaire below, using google form (D1). During the introduction and questionnaire filling, the participants were free to ask questions and give comments. The statistic result of the questionnaire are shown in Figure 25, the main comment and concerns are in D2.

D.1 Preference questionnaire

The questions are below. Figures for undstanding the describtions are shown in figure 22-24.
Please choose the design elements you prefer:
Q1: cleaning different dirts:
C1: different cleaning pads
C2: rotated/static cleaning pads
C3: mini vacuum cleaner + mopping pad
Q2: Clean narrow places (figure 22):
C1: robotic arm
C2: clean in different directions
C3: small size
Q3: Self-cleaning (figure 23):
C1: drop the used pads and equip unused pads.
C2: drop the used pads and equip unused pads.
C3: inner vacuum system & washing and ventilation system
Q4: Handle dirt after cleaning, you need to
C1: empty the trash can
C2: empty the trash can
C3: empty the trash can and change water.
Q5: Overall, which is your favorite device concept? (figure 24).
C1: Integrated
C2: Transformer
C3: Cubes

D.2 Questionnaire results

The results consist of two parts. The first part is the following part shows the transcriptions of their comments on the concepts and explaination of their choice. The second part is a statistical graph illustrates quantitative results of the test.

Chinese participant 1

- The robotic arm in concept 1 can clean the higher place but it might be difficult to aim the point.
- Whether the cleaning part of concept 2 can be lifted or lowered? Besides, I don't want to bend over

Chinese participant 2

- The preference depends on the degree of cleanliness it can clean (only concerned about the result rather than the methods)
- It seems that there are too many small things in Concept 3 and it's difficult to control, but I like the small size and feel very flexible.
- If the price of the substitute part is appropriate, don't mind the disposal pads in concept 1 and 2.

Chinese participant 3

- The concept3 of the product looks more flexible, although I don't like to change the water, I don't want to buy a new one from an economic point of view, I think 3 is cheaper.
- Water changing can also be automatic (toilet water.

Chinese participant 4

- Products can be formed by big and small parts, not only the same size.
- The self-cleaning idea of Concept 3 looks more environmentally friendly
- Concept 2 is very straightforward because the buttons are on the product, you can command it immediately.

Chinese participant 5

- The clean part is not disposable, it is more environmentally friendly and saves money.
- Is it possible to select components? So I can choose to change the water or buy disposal products.
- It's ok, but I don't want to clear the water tank.
- Use bamboo charcoal to suck dirty things? Then change the filter?
- If the water pipe is connected, it will be inconvenient in the existing home installation,

- but it may be convenient if the pipeline is integrated in the future.

Dutch participant 1

- Concept 3 focus on one thing, small but clear, while others are too much, I'm not sure if it professional enough.
- The self-cleaning way of concept 3 is better for the environment.
- I don't think change water is a big task, it is only behind empty the trash can.
- Also buying new pads is a bigger step than changing the water.

Dutch participant 2

- (Concept 1) all pads work one behind each other is efficient.
- Concept 1 and 2 only have one working direction, which is not flexible.
- Concept 3 is more sustainable, but hope the machine can automatically change the water.

Dutch participant 3

- (Concept 1) For me, it is more logical using different pad to clean different dirt.
- (for not choosing concept 3) I don't want to change the water. Especially the dirty water. I don't want to touch dirt.

Dutch participant 4

- (Concept 2) It looks integrated and stable. I'm not sure weather the robotic will operate exactly. For the mini robots, they are cute, but a little bit out of control for me.
- How do the used pads gathered? The dirty ones are on the top, how does it works?

Dutch participant 5

- (Concept 3) It looks like sending a few elves. I like it.
- (Concept 3) Small, it seems that it can't be fixed and easy to move.

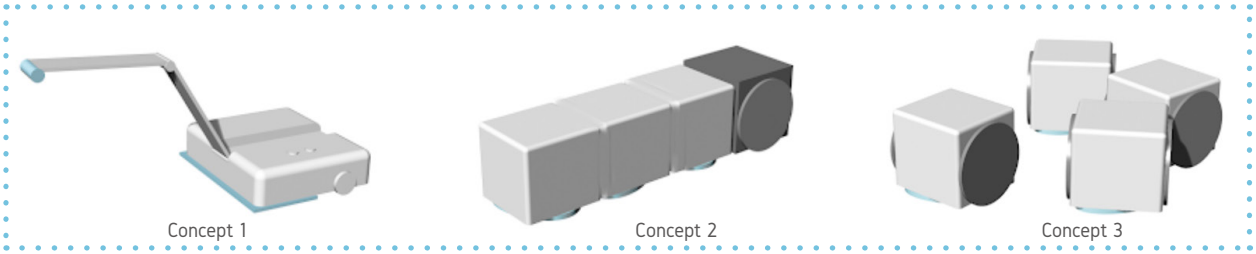


Figure 22. Clean narrow places

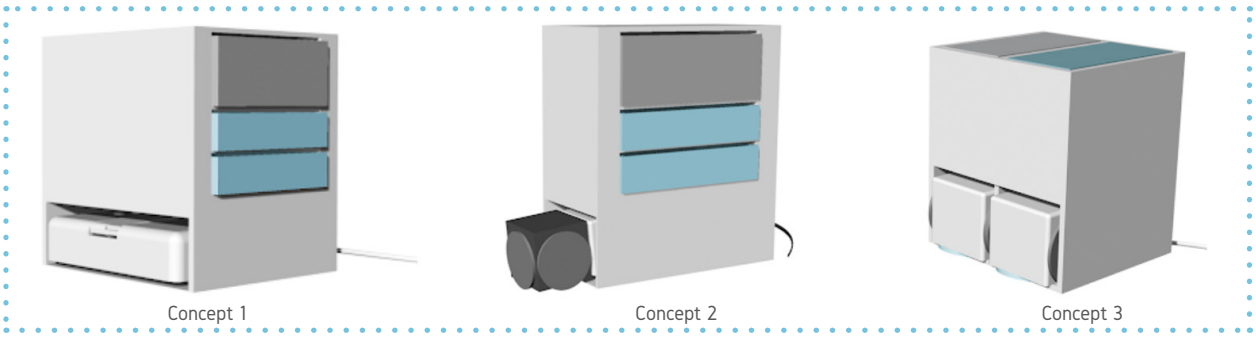


Figure 23. Self-cleaning

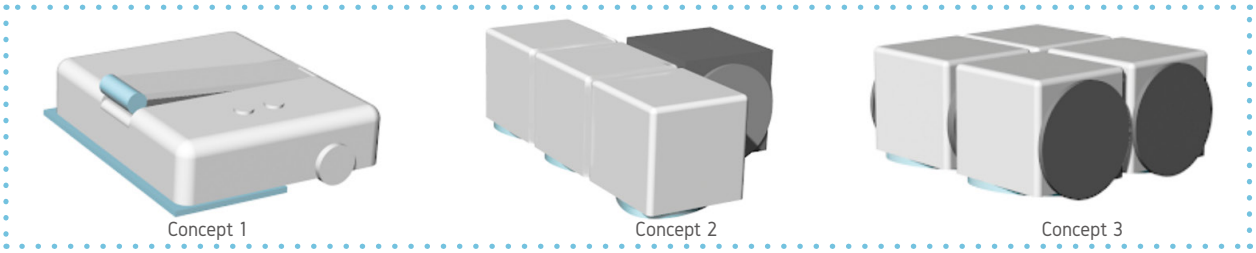


Figure 24. Overall concepts

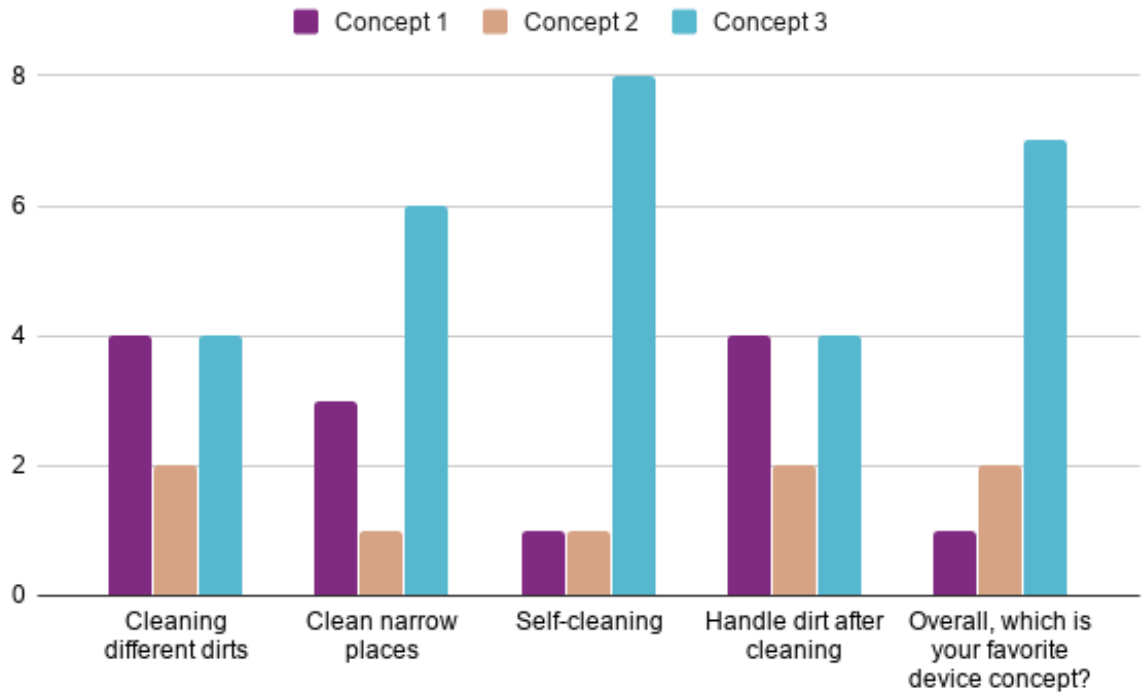


Figure 25. Statistic result of the early concept test

E. Interaction concepts evaluation

E.1 Materials for the three concepts evaluation sessions

The materials that used in the three concepts evaluation include slides (Figure 26-30) for demonstrating the device concept and a questionnaire (Figure 31) for scoring each step. The images shown below are all animated during the test.

Figure 26. Overall introduction

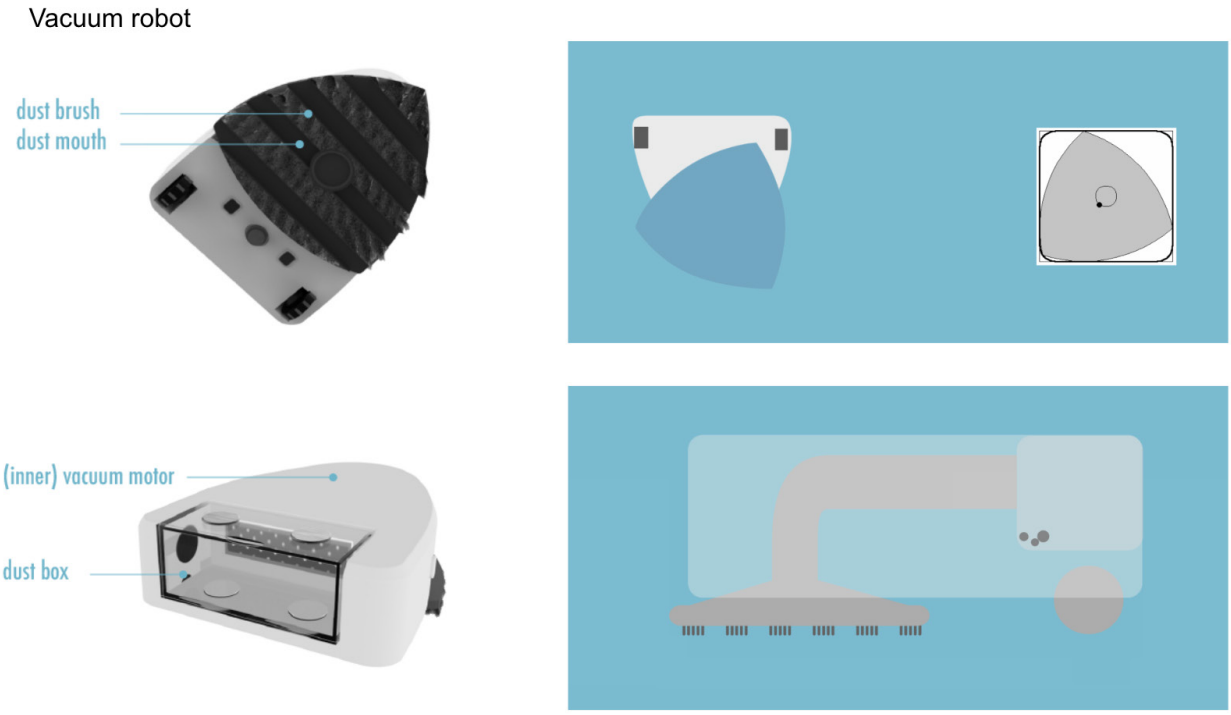


Figure 27. The structure of the cleaning pads

Mopping robot

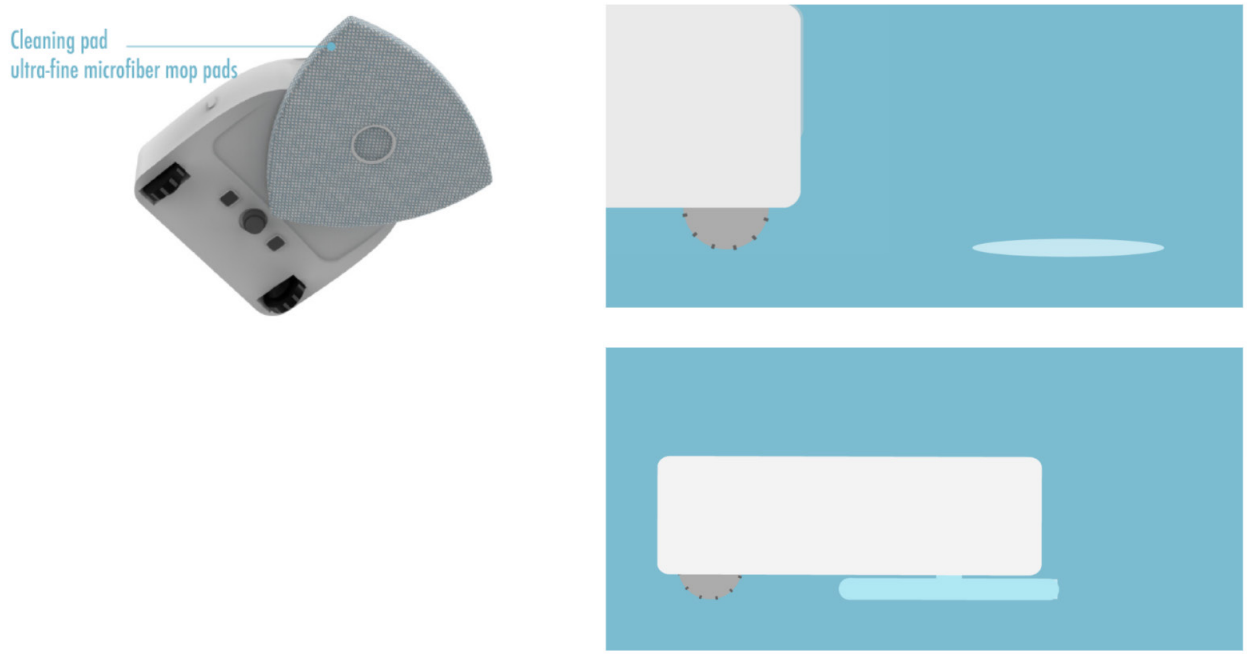


Figure 28. The sensors in the two cleaning robots

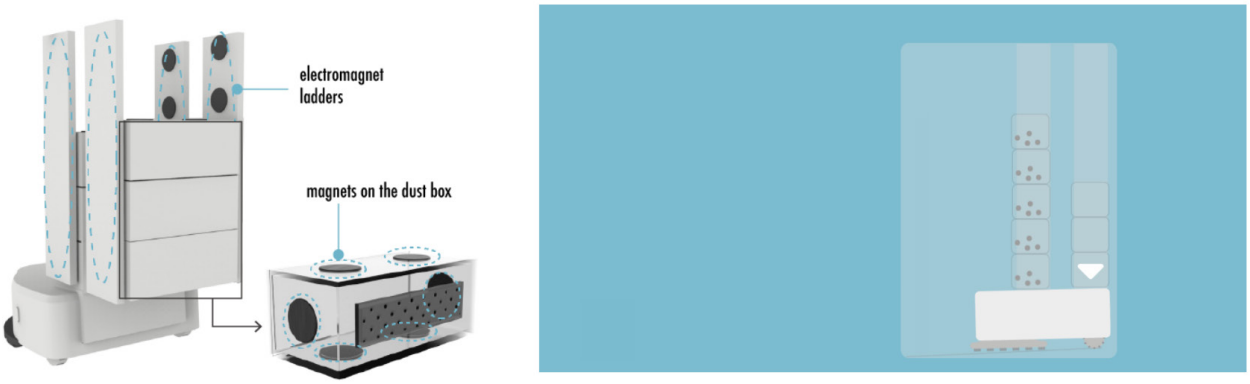


Figure 29. Inner box changing system

Figure 30. Inner washing & ventilation system

Participant' s number: _____

Please score the trustworthy and effortless of each interaction concept
-2(lease) to 2(most)

Step		Concept 1	Concept 2	Concept 3
1 install the device	Trustworthy			
	Effortless			
	Other comments			
2 timely cleaning (try out)	Trustworthy			
	Effortless			
	Other comments			
3 start a timely cleaning task	Trustworthy			
	Effortless			
	Other comments			
4 cancel a timely cleaning task	Trustworthy			
	Effortless			
	Other comments			
5 Set a schedule	Trustworthy			
	Effortless			
	Other comments			
6 garbage disposal / emergency response	Trustworthy			
	Effortless			
	Other comments			
7 later stage of use	Trustworthy			
	Effortless			
	Other comments			
8 Overall impression				

Figure 31. Evaluation questionnaire

E.2 Results of the three concepts evaluation

Table 2-1. Scores of each step

Step 1	Concept 1		Concept 2		Concept 3	
	Trust	Effortless	Trust	E	T	E
P1	-2	1	0	0	2	0
P2	0	1	0	-2	1	0
P3	0	2	2	-1	0	-1
P4	1	1	2	2	2	1
P5	1	1	2	2	0	0
P6	1	2	2	2	2	1
P7	0	0	2	2	2	2
P8	1	1	2	2	0	0
P9	-1	-2	-1	2	-2	0
P10	1	2	1	1	2	2
Average	0.2	0.9	1.2	1	0.9	0.5

Step 2	Concept 1		Concept 2		Concept 3	
	Trust	Effortless	Trust	E	T	E
P1	1	2	0	2	2	1
P2	0	1	1	1	0	-1
P3	0	-1	2	2	1	2
P4	1	0	2	2	2	2
P5	1	1	1	2	1	1
P6	2	0	2	2	2	2
P7	1	1	-1	-1	2	2
P8	1	1	1	2	1	1
P9	2	2	2	2	0	2
P10	1	1	0	2	2	2
Average	1	0.8	1	1.6	1.3	1.4

Step 3	Concept 1		Concept 2		Concept 3	
	Trust	Effortless	Trust	E	T	E
P1	0	2	2	2	2	1
P2	1	1	0	1	0	-2
P3	-1	2	2	0	1	2
P4	1	2	2	-1	2	1
P5	2	2	2	1	1	1
P6	1	1	2	2	2	2
P7	2	-1	2	2	2	2
P8	2	2	2	1	1	1
P9	1	2	2	1	0	2
P10	1	2	2	2	2	1
Average	1	1.5	1.8	1.1	1.3	1.1

Step 4	Concept 1		Concept 2		Concept 3	
	Trust	Effortless	Trust	E	T	E
P1	2	2	1	2	2	1
P2	0	0	1	-1	0	0
P3	0	1	1	-2	0	0
P4	0	-1	1	1	2	0
P5	2	2	1	1	0	0
P6	2	2	2	2	1	-1
P7	2	2	0	0	-2	-2
P8	2	2	1	1	0	0
P9	2	2	0	1	2	2
P10	2	0	1	0	2	2
Average	1.4	1.2	0.9	0.5	0.7	0.2

Table 2-2. Scores of each step

Step 5	Concept 1		Concept 2		Concept 3	
	Trust	Effortless	Trust	E	T	E
P1	2	1	2	0	2	0
P2	0	-1	-1	2	1	-2
P3	2	1	-1	0	0	-2
P4	1	0	2	2	2	1
P5	1	1	1	0	0	0
P6	2	1	2	2	2	0
P7	2	2	2	2	2	2
P8	1	1	1	0	0	0
P9	2	2	2	1	2	1
P10	1	2	1	1	2	1
Average	1.4	1	1.1	1	1.3	0.1

Step 6	Concept 1		Concept 2		Concept 3	
	Trust	Effortless	Trust	E	T	E
P1	0	1	0	1	2	1
P2	1	1	1	1	2	2
P3	2	0	2	1	2	1
P4	1	0	2	2	2	2
P5	2	2	2	0	2	2
P6	1	2	2	2	2	2
P7	1	1	-1	1	2	2
P8	2	2	2	0	2	2
P9	-1	2	2	-1	2	1
P10	0	-1	2	2	2	2
Average	0.9	1	1.4	0.9	2	1.7

Step 7	Concept 1		Concept 2		Concept 3	
	Trust	Effortless	Trust	E	T	E
P1	2	2	2	2	1	1
P2	-1	1	-1	-2	-2	-2
P3	0	1	1	0	0	1
P4	-1	2	1	2	2	-2
P5	2	2	2	1	0	0
P6	0	2	2	2	1	-1
P7	2	2	2	2	1	1
P8	2	2	2	1	0	0
P9	-2	2	0	1	2	1
P10	1	0	1	2	2	-1
Average	0.5	1.6	1.2	1.1	0.7	-0.2

Table 3. Comments on concept 1

	Trustworthy		Effortless	
	Negative	Positive	Negative	Positive
Step 1	Confused about the facial recognition system and the cleaning logic.	Looks smart and advanced, so they have high expectations. The place is obvious and easy to remember.	Don't want to have too many introductions to learn in the begining.	
Step 2			Too many buttons. cannot understand the meaning in a short time.	
Step 3	Worried about the cleaning logic. it might clean too many times. Wonder if it can detect the location of all the garbage.	The trust is based on the cleaning ability of the device.	You need to manually start if it cannot sense accurately.	
Step 4		It's on the outside, so others can also see it.		It's relate to the bath-room context, you can reach it conveniently.
Step 5		Like setting the alarm clock. It's familiar, so it's trustworthy.	Move the items is not effortless. Hope the schedule can also be set automatically.	
Step 6	The blinking icon might be ignored.		Manually dispose the contaminants is not easy.	
Step 7	not sure if the algorithm is accurate. don't want it only clean a certain place. Too many functions. Just want to know the most improtant one.			It can safe time and effort (if it can clean properly)

Table 4. Comments on concept 2

	Trustworthy		Effortless	
	Negative	Positive	Negative	Positive
Step 1		Already know the interaction form of mobile APP and the workflow is clear.	A lot of things to lear,n especially the passwords of the voice control.	
Step 2			Not easy to find the APP if in a hurry.	With the help of voice control will be fine
Step 3	Worried about the accuracy of speech recognition. The time setting is not accurate if do not have a daily routine.		Feel strange/un-safe/lazy to ask by voice.	The feedback with voice is obvious
Step 4		The feedforward of the voice is clear.	The feedforward bothers the user, and the user have to think and make decision.	
Step 5			Voice is too timely and without enough consideration. The feedback is not obvious and might be forget.	The operation on App/screen is more deliberate. The feedback on App is obvious.
Step 6	It should not talk without permission. The feedback on app might be forget.			
Step 7			It should adapt itself actively, not bother the user. Seeing a lot of schedule on the App is troublesome.	

Table 5. Comments on concept 3

	Trustworthy		Effortless	
	Negative	Positive	Negative	Positive
Step 1	The remote control is very tradition and trustworthy.		The storage of the remote control and changing the battery isn't easy. Only 5 buttons is needed, but not one more device.	The istall is very simple. The remote control is direct (don't need to point many times.)
Step 2			The remote control might fit the elder people.	
Step 3				
Step 4				
Step 5			Too much information. Don't want to see too many history tasks. Don't need app to make a decision. only need to see the floor.	
Step 6	The light might be ignored.	The light on the device is not bother and is direct.		
Step 7			Too stupied. Won't regard it as a smart product.	Might consider it if it's cheap.

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 _____
initials _____ given name _____
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 ( ) SPD
2nd non-IDE master: _____
individual programme: __-__-____ (give date of approval)
honours programme: ( )
specialisation / annotation: ( )
( )
( )

SUPERVISORY TEAM **

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

** chair _____ dept. / section: _____
** mentor _____ dept. / section: _____
2nd mentor _____
organisation: _____
city: _____ country: _____

comments (optional)

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 _____ date ____-____-____ signature _____

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: _____ EC

Of which, taking the conditional requirements into account, can be part of the exam programme _____ 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 _____ date ____-____-____ signature _____

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

comments

name _____ date ____-____-____ signature _____

Initials & Name _____ Student number _____

Title of Project _____

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 - - 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, ...).

space available for images / figures on next page

Initials & Name Student number

Title of Project

introduction (continued): space for images

image / figure 1:

image / figure 2:

Initials & Name _____ Student number _____

Title of Project _____

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.

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.

Initials & Name _____ Student number _____

Title of Project _____

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 ____-____-____ ____-____-____ end date

Initials & Name _____ Student number _____

Title of Project _____

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.

FINAL COMMENTS

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

Initials & Name _____ Student number _____

Title of Project _____