

# Towards a Smart Bathroom Maid

Y. Wang Author





## Towards a Smart Bathroom Maid

by



to obtain the degree of Master of Science at the Delft University of Technology, to be defended publicly on Thursday Novenmber 21, 2019 at 2:00 PM.

Course: ID4290-16 Graduation project (DFI) Student number: 4695097 Thesis committee: Prof. dr. Horváth, I., TU Delft, Chair Kooijman, A., TU Delft, Mentor



#### CONTENTS

CC	NTENTS	3
Ех	ecutive summary	7
1.	Reporting on orientation	8
	1.1. Context introduction	9
	1.2. Problem definition	11
	1.3. Assignment	11
	1.4. Planning and approach	12
	1.5. motivation and personal ambitions	12
2.	Reporting on process results and analysis	14
	2.1. Overview of the objective	15
	2.2. Overview of the research methods	16
	2.3. Study I: Understanding the bathroom context	17
	2.3.1. Research questions and methods	17
	2.3.2. Results and analysis	17
	Bathroom environment	17
	Smart appliances in the bathroom	18
	Benefits of a smart bathroom	19
	Future bathroom trend	20
	2.3.3. Key takeaways	21
	2.4. Study II: Understanding the human context	22
	2.4.1. Research question and methods	22
	2.4.2. Results and analysis	22
	Social background and users	22
	Activities	23
	Needs of users	24
	Stakeholders	25
	2.4.3. Key takeaways	25
	2.5. Study III: Understanding the bathroom cleaning context	26
	2.5.1. Research questions and methods	26
	2.5.2. Results and analysis	26
	Dissatisfaction of users	26
	Hygiene problems	28
	Operation	29
	2.5.3. Key takeaways	30
	2.6. Study IV: Analysis of artifactual enablers	31
	2.6.1. Research question and methods	31
	2.6.2. Results and analysis	31
	Targets of intelligent system	31
	Principle of CPS	32
	Sensor selection analysis	32
	2.6.3. Key takeaways	33
	2.7. Study V: Interaction exploration	34
	2.7.1. Research questions and methods	34
	2.7.2. Results and analysis	34
	Interactions between human and smart products	34
	Interactions between human and bathroom & interaction between bat	throom

	and smart products(maid)	35
	2.7.3. Key takeaways	36
	2.8. Study VI: Market analysis	37
	2.8.1. Research questions and methods	37
	2.8.2. Results and analysis	37
	Company development focus	37
	Analysis of the reasons why consumers do not use smart bath	oom
	products	38
	New trend: retrofit model	38
	2.8.3. Key takeaways	40
	2.9. Synthesis: Convergence of insights	41
	2.9.1. Personas	41
	2.9.2. Future bathroom vision	42
	2.9.3. User value	43
	2.10. Orientation of design	44
	2.10.1. Design requirements for product concept	44
	2.10.2. Design requirements for interaction concepts	44
3.	Ideation and conceptualization	46
	3.1. Introduction of ideation & conceptualization	47
	3.2. Design goal	48
	3.3. Product concepts	49
	3.3.1. Brainstorm	49
	3.3.2. Introduction of product concepts generation	49
	3.3.3. Concept 1: Drain oriented (C86)	50
	3.3.4. Concept 2: Toilet oriented-1 (P37)	51
	3.3.5. Concept 3: Toilet oriented-2 (149)	51
	3.4. Evaluation of product concepts	
	3.4.1. The objective of evaluation	52
	3.4.2. User test setup	
	3.4.3. Results	54
	Concept 1: Drain oriented (C86)	54
	Concept 2: Tollet oriented -1 (P37)	55
	Concept 3. Tollet oriented-2 (149)	55
	2.4.5. Kov tekoowovo	30
	2.5. Final product concept	00 50
	2.5.1 Einel product concept	00 50
	3.5.2. Validation	
	3.5.2. Valluation	61
	3.6 Interaction concents	01
	3.6.1 Introduction	02
	3.6.2 Concept 1: High-level smart (T00)	63
	3.6.2.1 Main functions description	03
	3.6.2.2. The embodiment of cyber-physical system principles	05
	3.6.3. Concept 2: Middle-level smart (P32)	05
	3.6.3.1 Main functions description	00
	3.6.3.2 The embodiment of cyber-physical system principles	00
	3.6.4 Concept 3: Low-level smart (C54)	70
	3 6 4 1 Main functions description	72
	3.6.4.2. The embodiment of cyber-physical system principles	73

3.6.5. Constraints	74
4. Evaluation of interaction concepts	76
4.1. The objective of evaluation	77
4.2. User test setup	77
4.3. Results	79
4.3.1 Concept 1: High-level smart (T99)	80
4.3.1.1 Evaluation results	80
4.3.1.2 Evaluation results analysis	81
4.3.1.3. Key takeaways	81
4.3.2. Concept 2: Middle-level smart (P32)	82
4.3.2.1. Evaluation results	82
4.3.2.2. Evaluation results analysis	83
4.3.2.3. Key takeaways	83
4.3.3. Concept 3: Low-level smart (C54)	84
4.3.3.1. Evaluation results	84
4.3.3.2. Evaluation results analysis	85
4.3.3.3. Key takeaways	85
4.4. Conclusion	86
4.5. Validation	87
4.6. Constraints	87
Reference	89
Appendix A: Approved design brief	90
Appendix B: An example of contextmapping interview	97
Appendix C: Questionnaire form	99
Appendix D: Insights of questionnaire research	101
Appendix E: User test form of product concepts	104
Appendix F: An example of user test form	106
Appendix G: Remarks and suggestions	108
Appendix H: User test protocol	109
Appendix I: User test form of interaction concepts	110
Appendix J: Comments of interaction concepts	112

This page is intentionally left blank.

#### **Executive summary**

This is an eight-month master's graduation program. My main research direction is how to make it more convenient for users to clean a private bathroom through a technical solution, also known as "smart bathroom maid." Considering that this is an exploratory project, there are too many unknown areas, so the final result is not a complete intellectualized product-service system, but a design direction towards this end. This project is conducted in three phases.

#### Phase 1: Analysis

The analysis phase of the project can be grouped into studies: (i) human, (ii) bathroom, (iii) cleaning, (iv) artifactual enablers, (v) interaction, and (vi) market. User's in-bathroom activities can be sorted into groups of activities related to using a bathroom and cleaning a bathroom. These two activities have to consider two dimensions: present and future. Therefore, each study needs to consider these four circumstances: present using, present cleaning, future using, future cleaning.

For each study, I have raised one or more research questions to guide my research direction. I employed several techniques to answer study questions, including contextmapping interview, questionnaire research, observation. Those techniques help me discover user insights. Besides that, I construct the theoretical knowledge system by literature research, keywordbased internet search. In the end, I chose the most useful insights as key takeaways for each study. So as to give a good view prior to the conceptualization, I converged key insights into personas, user values, design requirements, etc.

#### Phase 2: Ideation and conceptualization

Based on the results of the analysis, I entered the next phase: ideation and

conceptualization. This phase is divided into two parts: product concept generation and interaction concepts exploration. Regarding the product concept generation, the design scenes are the bathroom (i) after using the toilet and (ii) after bathing. The goal is to select one scene to generate final product concept. The retrofitting and cleaning function is the focus of this process.

In interaction concepts exploration process, I distinguished 3 interaction concepts based on different smart level. The smarter the system, the more the system does for people. Exploring the impact of different smart level systems on the interaction of users is the focus of this process. The generation of 3 interaction concepts is in line with the principles of cyber-physical system.

#### Phase 3: Evaluation

After that, I conducted qualitative evaluation tests. Ten participants were invited to participate in the final evaluation test. I prepared the prototypes (both hardware and software) and PowerPoint for the participants to experience 3 interaction concepts. Afterwards, I analyzed results according to participants' scores and verbal feedback for each concept, and reached the final conclusion. At the same time, I also found the constraints of the evaluation process, which are listed in the report. These findings will provide design ideas for the near future smart in-bathroom product design. So far, my project has been closed.

Thanks to my Chair Imre and Mentor Adrie for guiding and helping me in the project. The adequate and critical feedback from them helped me to learn a lot from this project. I am also grateful to the students who participated in the research and testing. Their feedback is of great significance to the final results.

# 1. Reporting on orientation

#### 1.1. Context introduction

The topic of this project is exploring design directions towards a smart private-bathroom service/product. It is often the case that a bathroom is used by multiple people after each other. They always like having a cleaned bathroom when it comes to using it. Typical examples for private shared bathrooms are, such as dormitory- and family bathrooms. These bathrooms are used by two or more people. The difference in the personal using and cleaning habits causes inconveniences to the user who

Bathroom With Suboptimal Hygiene Intervention

buildings more automated and multifunctional. The current smart homes are supposed to satisfy very diverse and unique needs, such as bathroom cleaning. But they must be equipped with proper equipment for doing this task with a high level of smartness and automation, which not disturbing the dwellers. A "smart maid" can be foreseen as a technical solution. Like a real maid, it can assist the bathroom users not only in performing some tasks, but also cleaning the bathroom when these



**Bathroom With Adequate Hygiene Intervention** 

Figure 1.1-1: Comparison of bathrooms in different hygiene interventions

uses the bathroom later. The other end of the coin is that each users would like to have some automatic technical solutions, which provide services to facilitate the intricate task of bathroom cleaning. This objective can be achieved by the rapidly developing cyber-physical system technologies.

The convergence of physical and cyber technologies, such as big-scale sensing, real-time system control, and big data analytics, has made it possible to make are done (see Figure 1.1-1). A clean and hygienic bathroom will provide its users with a comfortable experience, allowing them to use the bathroom with confidence and satisfaction. In order to achieve it, a "smart maid" will be considered in this project with capabilities, such as recognizing activities of individuals and even following up on those. Having a smart maid, a pleasant experience can be produced for the bathroom users at reasonable price and effort. However, the smart maid should be aware of the bathroom, the dirt in the bathroom, and the need of the bathroom users.

This project aims at providing a new solution for a convenient bathroom usage. It will mainly consider the usage of the bathroom and intend to support it by bathroom cleaning services provided by a smart maid. Towards this end, it will consider the interaction of the users with the bathroom, the interaction of the smart maid with the bathroom, and the interaction of the bathroom with human being (see Figure 1.1-2). Since this project belongs to the DFI orientation, the focus will be put on the relationship of the new smart

solution with various bathroom users and in addition attention will be given to the range of functionalities what the smart maid can provide as cleaning services for the bathroom. As the result of the provided services, the previous use of the bathroom will not directly affect the subsequent user, and allows better experiences in general. The approved design brief can be seen in Appendix A.



Figure 1.1-2: Conceptual interactions

#### 1.2. Problem definition

#### 1.3. Assignment

The project is done as an explorative study. Its scope will be as follows:

- Understand the context of using a shared bathroom by multiple individuals. Typical time periods (i) when the bathroom is in great demand, (ii) after using toilet, (iii) after bathing, will be selected for the research.
- Understand the applicability of the principles of cyber-physical system (CPS) at creating a "smart maid" that provides various services for cleaning and tidying the bathroom for subsequent users.
- Examine the cleaning tasks which are needed to avoid inconvenience for the subsequent user.
- Understand and explore the various forms of interactions between the user the bathroom, the user and the smart maid, and the smart maid and the bathroom.

The explorative study will consider the aforementioned interactions in the bathroom usage and cleaning context. In addition, the overall concept of cyber-physical system will be studied with special attention to the operational principles, the provided functionality and smart control. Various sources of knowledge will be used for this purposes, such as academic literature, Internet repositories, user studies and environmental investigation. The technology oriented research will be used to generate requirements for the functionalities of the "smart maid" and to aggregate knowledge for the possible implementations. The other studies will mainly include the investigation of the achievable human behavior, automated cleaning technologies, hygiene monitoring by sensors.

The "smart bathroom maid" will be conceptualized as a intellectualized productservice system, including software and hardware design. It can be used to reduce or diminish the inconvenience caused by previous use and to provide a new way of interaction between the "smart bathroom maid" and the users.

Various domains of knowledge will be visited in order to provide a proper solution for interaction of the people with the smart maid. The result will not be a realized complete system, but a framework which indicate some feasible design directions and offers a consolidated pattern of interaction. These two will be verified by demonstrative tests.

#### 1.4. Planning and approach

There will be six milestone meetings during this project (kick-off meeting, analysis reporting meeting, midterm go/no go meeting, prototyping reporting meeting, green light meeting, colloquium and graduation ceremony). In order to have a good preparation for these meetings, corresponding reports and other materials (e.g., presentation slides) will be handed over to the chair and the mentor before the meeting to ensure they have sufficient time to review it. Furthermore, a demonstrative prototype will be developed together. With regards to the instrumentation needed, Arduino electronics will be used to simulate specific interactive functionalities of the "smart maid", which will show the potential design directions towards a "smart bathroom maid" and present interaction scenarios.

The entire design process is divided into five phases: research, ideation, prototype making, validation, documentation. In the research and validation phases, because there is a need to contact the users, there will be an interviewee finding time around 5-hour per week. Apart from a fixed 1.5hour coach meeting per week, in these two phases, there will be around 33.5-hour of knowledge generation time per week, and the rest three phases will be about 38.5hour per week.

# 1.5. motivation and personal ambitions

Out of concern for the application of Cyber-Physical System technology and the desire to enrich knowledge of this field, I am motivated to start researching this project.

- My competences which are helpful to this project are as follows:
- I have rich experience about how to conduct user research.
- My living environment makes it easy for me to access private bathroom users.
- I joined two electives to learn IoT and TCD design methodologies which are correlated with CPS technology. I have the knowledge of Artificial Intelligence and Machine Learning as well as sensor-based research.

Here are what I want to learn through this project:

- How the principles of cyber-physical systems can be used to develop the smart maid.
- Technical feasibility issues (e.g., human behavior recognition technology, hygiene monitoring sensors and other means).
- Demonstration of the interaction features for users (i.e., how to simulate specific functionalities with limited programming knowledge and materials.).

My ambitions are as follows:

- To implement a demonstrative means which lends itself to testing specific smart functionalities.
- Enrich my programming knowledge and use Arduino as much as possible for research and testing.

In general, this is a complex and explorative project with many unknown areas. For instance, I need to understand the principles of cyber-physical systems which can be used to construct the functionalities of the "(future) smart maid"; I need to investigate the individual's in-bathroom activities which is a private topic that is not open hearted for each interviewee to describe, etc. That is why I consider that the final result of the project is not necessarily to be a complete "smart maid" system, but can provide potential design directions towards a "smart bathroom maid".

# 2. Reporting on process results and analysis

#### 2.1. Overview of the objective

In the focus of the project is the relationship of a new smart bathroom cleaning solution with various bathroom users. In addition, attention will be given to the range of functionalities that the smart maid can provide as cleaning services for the bathroom. The research activities completed in the analysis phase can be grouped into studies: (i) human, (ii) bathroom, (iii) cleaning, (iv) artifactual enablers, (v) interaction, and (vi) market. The reasoning model can be seen in Figure 2.1. The in-bathroom activities can be sorted into the groups of activities related to using a bathroom and cleaning a bathroom. If I would study only the present situation, my design would only be a new solution to the existing problem. A future vision of a private bathroom is probably helpful to broaden the design space. Therefore, research phase of the project will study above two types of inbathroom activities from two dimensions: present and future. In summary, each study should reflect these four circumstances: present using, present cleaning, future using, future cleaning (see Figure 2.1).



Figure 2.1: Reasoning model about the context of research

# 2.2. Overview of the research methods

This is a curiosity-driven research. I have raised questions for each research study. With the questions as the basis, I chose the proper research methods to collect data in a targeted manner. The data from the study will answer the question from the aforementioned four circumstances from a neutral perspective. My research methods consist of: interviews, observations, questionnaire survey, literature and keyword-based internet search (see table 2.1).

Study type	Research methods				
Study I: Understanding the bathroom context	0			$\widehat{\mathcal{Q}}$	
Study II: Understanding the human context				$\widehat{\mathcal{O}}$	Ξ
Study III: Understanding the bathroom cleaning context				$\widehat{\mathcal{O}}$	ij
Study IV: Analysis of artifactual enablers					
Study V: Interaction exploration				(;) ()	:=
Study VI: Market analysis				$\widehat{\mathcal{Q}}$	Ξ
Disterviews Observations					

Table 2.1: Overview of the research methods.

Keyword-based internet search

#### 2.3. Study I: Understanding the bathroom context

#### 2.3.1. Research questions and 2.3.2. Results and analysis methods

This project is to provide a technical solution for users who share private bathrooms with others, so understanding the bathroom and (smart) bathroom products is able to systematically frame the bathroom environment. Literature research is needed to theoretically understand the basic composition the bathroom, the characteristics of the smart bathroom, and the future development trend. By observations and interviews, I experienced the real user environment, such as products usage conditions, etc. Keywords internet search can broader the understanding of existing smart bathroom products. My study questions are:

> "What is the smart bathroom and how does the future bathroom like?"

Bathroom environment

The book (Deschamps-Sonsino, A., 2018) describes the evolution of bathroom. As a result of Public Health Act of 1875, a indoor toilet has become a must-have in any new buildings. After that, with the construction of the city-wide sewage system, sinks and running water has appeared indoors. With the development of sanitary materials, such as flushing toilet, new industries was kicked off. In November 1984, the American National Association of Home Builders (NAHB) organized with a 2-day event titled "smart home", and this is the first use of the term "smart" in the home context (Deschamps-Sonsino, A., 2018).

It can be seen from the evolution of the bathroom that the bathroom must first meet the basic needs of people's grooming, and then make people's lives more convenient through "smarts". In order to satisfy people's basic needs, a range of products has appeared in the bathroom. By observation and keyword internet search to collect information, I have divided these products into three categories based on their functions and usage (see table 2.3.2).

Fixed appliances and facilities:						
Tollet Shower head Exhaust fan Tub						
Mirror Faucet Shelves Others						
Unfixed tools:	Unfixed tools:					
Bulbs	Hair dryer	Toothbrush	Towels			
Trash bin	Trash bin Plunger Others					
Consumable products:						
Paper roll	Soap	Shampoo	Others			

Table 2.3.2: Categories of in-bathroom products.

These products allow the basic functions of the bathroom to be realized:

- Various water usage and drainage
- Lighting
- Deodorizing

After meeting the basic functions of the bathroom, the emergence of smart products brings convenience and pleasure (Deschamps-Sonsino, A., 2018) to the use of the bathroom. Through internet search, I found that most of the smart products are embedded in fixed appliances (see Table 2.3.2) (i.e., to make appliances smart). At the 2018 KBIS show, many companies exhibited the latest research and development of smart bathroom products, which reveals to some extent the development trend of the future bathroom. The article (Askar, N., 2018) summarized four categories of smart bathroom products that showed at the KBIS exhibition (see Figure 2.3.2 to get an impression):

- Smart toilets
- Smart showers and tubs
- Smart faucets
- Smart mirrors

As mentioned in the article, smart toilets have been developed by major companies. However, each company's focus is different, such as energy and water conservation, health monitoring and so on. Toilet cleaning is only a small part of it involved.

Smart showers and tubs address different bathing needs. With regard to showers, companies have introduced a range of controllers, such as precise watertemperature control, steam control and more. The tub is more focused on automatic water storage and drainage, and smart massage functions.

There are smart faucets whose main function is to save water, save energy and improve hygiene. The last category is smart mirror, whose main function is defogging and illuminating.



Figure 2.3.2: Four categories of smart bathroom products that showed at the KBIS exhibition

So what is the purpose of developing smart products? The paper (Watson et al, 2018) proposed several benefits of a smart bathroom for users. I grouped them into three points:

- Water and energy saving
- Empowering users with greater consumption understanding
- · Good for health and wellness

Water efficiency has grown rapidly due to the increasing shortage of water resources. Data from digital/intelligence meters has been used to evaluate water management demands. In the short term, this data can be used to improve facility management, such as water loss and breakages, usage patterns to inform cleaning management. Since water and energy consumption are directly related, especially the use of hot water, the ability to control and adjust water temperature and hot water usage habits can provide potential for energy savings.

Empowering customers and users with information about their consumption patterns and uses will allow them to make informed decisions about how they use water in the future. It also empowers users to develop a greater understanding of their consumption (Liu & Mukheibir 2018). For example, instead of guerving a piece of historical consumption data, users can monitor water or energy consumption in real time through a smart meter. Furthermore, advancements in mobile applications are facilitating fast and simple management of personal and household activities, but the success of these applications depends on access to relevant and useful information which relies on the development of "Internet of things" (IoT).

Smart bathrooms are closely related to

people's health and wellness. For instance, the ability to vary lighting levels in response to ambient light not only saves energy, but also has proven health and wellness benefits for inhabitants (Chew et al 2017). Similar benefits have been shown from smart ventilation systems which adjust the airflow across the building based on CO2 levels, humidity, occupancy and outdoor temperature. The overall housing development trend in the future will have an impact on the design of smart bathrooms. And this development trend also provides new ideas for designing smart products. Some practical issues need to be considered.

The challenge of the cities today and in the future is to solve the problems of affordable housing (Borsos et al, 2019). The topic of small living spaces has to be examined from two perspectives, (i) the number of newcomers to a certain area, and (ii) the increased price per square meter. This paper (Borsos et al, 2019) presents a vision of future home. In the future, as living spaces are diminishing, housing design needs to consider the following:

- In a living space, the size of the bathroom will be smaller, since it is a temporary function, which is not used constantly. Fast, quality and affordable housing is a daily topic.
- Modularity, which means easy to install and disassemble, will provide the ability to integrate into old buildings.

In addition to shrinking the per capita housing area, renting a house will also become a major form of residence. Renting a house will be a choice for them (people) for a long time (Askar, N., 2018). This trend will become more apparent over time. "An overwhelming number of U.S. residents have been leaning toward renting and leasing instead of owning, which also affects the market", says Bradly Egan, director of marketing at Niagara Conservation. Considering the future trend of bathroom, one thing is worth mentioning: apart from family users, tenants are even less willing to spend too much money in a shared environment. Because the living environment and the sharers are not fixed,

they will be more cautious when investing in shared smart products, questionnaire survey respondents repeatedly mentioned.

#### 2.3.3. Key takeaways

- 1. Users want to reduce the effort to install smart products.
- Users share a bathroom with sharers, so they are worried that expensive products will be damaged by the careless use of other sharers.
- 3. Today, "smarts" are embedded in fixed bathroom products.
- 4. In the future, more people will choose to rent and sharers are not always fixed.
- 5. Monitoring usage through smart products can help users to better understand their consumption.

Currently, the "smarts" of smart products is usually embedded in fixed appliances and facilities, such as smart toilets. This results in a lot of effort and money to install or replace these products. Modularity is a potential solution that allows users to quickly and easily install and disassemble "smarts" into bathroom or existing old products in their homes, reducing money and effort input.

One of the benefits of smart products is to give users a better understanding of their consumption, such as water consumption. By understanding, users can optimize their own usage habits to achieve the purpose of reducing expenses. Therefore, users can track their usage through an interactive interface of a smart product as a feedback.

In the future, on the one hand, the area of the bathroom will be smaller, which leads to the size of the smart product needs to take into account the reduction in the use area. On the other hand, more and more people will choose to rent and sharers are not always fixed, so affordable price of smart products is a concern of buyers.

#### 2.4. Study II: Understanding the human context

#### 2.4.1. Research question and 2.4.2. Results and analysis methods

The products in the bathroom constitute the physical environment in which the user's behavior and needs will shape or influence the bathroom. So it is important to understand the users of this project. I use contextmapping interviews (an example can be seen in Appendix B) and keywords internet search to learn about the user's bathroom activities. Literature research lets me theoretically understand the needs of users and stakeholders. Then, through the questionnaire survey (see Appendix C and Appendix D), the prioritization of user's needs is arranged. My study question is:

"What are the user needs?"

Social background and users

The users of (future) bathroom products can be divided into three groups (see table 2.4.2-1). All three user groups have a certain extent of acceptance for the smart bathroom products (see quotes in table 2.4.2-1).

Table 2.4.2-1: classification of (future) bathroom products users and quotes. (Quotes refer to the interview record of Dan DiClerico, home expert and smart home strategist at HomeAdvisor, at 2018 Kitchen & Bathroom Innovation Show (KBIS), from the article (Askar, N., 2018).)

User type	Quotes
Baby boom generation (1945- 1960)	", a lot of this technology is part of the strategy that will help them stay in their homes longer."
Gen Xers (1960- 1980)	", these innovations can be a huge help."
Millennials (1980- 2000)	", there's now the expectation of technology and innovation"

When choosing a user group, I made the following considerations. People aged 65 and older are the fastest growing population, especially in the Americas, Europe, and Asia. The U.S. Census Bureau reported that the number of people over the age of 60 is expected to reach 1.2 billion by 2025 (Thapliyal et al, 2018). This means that older people will stay longer than young people at home, so there are existing some smart products on the market targeting the healthy life of the elderly. The paper (Thapliyal et al, 2018) mentions plenty of research in this field.

However, as housing prices continue to rise, young people will face the economic situation of not being able to afford a house. Renting will be a form of residence which is probably to influence the smart bathroom

market, see Study I. Young people tend to become the main user group of tenants. There are not many studies on the young people yet. Additionally, considering the research population that I can approach, young people (millennials) will be my main research users in this project. They share a private bathroom with others.

With regard of the user group, I need to meet qualification, such as age, when selecting the respondent of interview and questionnaire survey. Towards this end, all respondents fit the qualification (see Appendix D). In order to understand the daily activities of the users, I interviewed 4 interviewees to make contextmapping (an example can be seen in Appendix B). The user's in-bathroom activities can be divided into two categories: using and cleaning. The examples of these two activities can be seen in table 2.4.2-2.

Using activities:					
Using toilet	Bathing	Washing face	Brushing teeth		
Shaving Combing hair		Blowing hair	Washing hands		
Face makeup Others					
Cleaning activities:					
Cleaning up any hair le	eft on the floor or sink.	Replacing the toilet paper roll when it's empty.			
Ventilating oder or spraying air freshener.		Cleaning up spills.			
Disinfecting the toilet s	eat.	Others			

In order to assist users in completing tasks of using and cleaning activities, a variety of smart products have emerged (see Study I).

"Wireless, touchscreen, intelligent controls, innovative steam dispersion and precision temperature control are becoming necessities. Innovative products that harness smart technologies to save time and offer convenience continue to gain in popularity.", says Martha Orellana, vice president of marketing at MrSteam Co.

This quote indicates that future smart products will meet people's needs in all aspects. What needs can be satisfied? I extracted a list of keywords from the article (Askar, N., 2018), which are the benefits of smart bathroom products mentioned by various sanitary companies leaders.

- Convenient
- Time-saving
- Personalizing
- Water-saving
- Energy-saving
- Easier to use
- Easier to clean
- Comfortable
- Enjoyable
- Safe

Through the form of a questionnaire, I showed these benefits to 51 respondents to explore their more urgent needs. The results of the question "Which of the following benefits do you want the smart product to bring to you?" can be seen in Chart 2.4.2, which helped me prioritize user's needs.

Which of the following benefits do you want the smart product to bring to you?



Chart 2.4.2: The results about users' needs of smart product.

"Easier to clean" and "convenient" are needed by 80% and 75% of respondents, respectively. "Time-saving" and "comfortable" have also met the needs of around 60% of respondents. "Water-saving" and "easier to use" have also met the needs of about 50% of respondents. The above points stand out from the list, especially "Easier cleaning" and "more convenient".

Moreover, from a company perspective, the benefits of adapting to user needs are a company's key competencies. Convenience would be the key argument to help companies sell new emerging technologies in the home space (Deschamps-Sonsino, A., 2018). As mentioned in this book, convenience refers to helping users simplify tasks. Users can spend less effort to complete or understand tasks. In addition to the main users, the needs of stakeholders can also be considered appropriately.

#### Landlord

As a landlord, they care about the usage of their house. It is a normal case that they check the cleanliness once in a long while. Sometimes, because of the long time span, tenants may cause irreparable problems. Therefore, landlords need a sense of security that their appliances are being used properly.

#### **Contractors and installers**

Bathroom products, especially smart bathroom products, often require professionals to install and repair. As mentioned in the article (Askar, N., 2018), finding product information is timeconsuming for contractors and installers. Therefore, they need a quick and convenient way to find product's information.

- 1. Landlord wants to remotely monitor the cleanliness of the bathroom.
- 2. "Easier to clean", "convenient", "timesaving", are most needed by users.

As I mentioned in the last Study, in addition to owning a house, renting is also a big trend in the future. Renting a home will result in non-fixed sharers, so that the risk of maintenance is high and users are reluctant to invest a lot of money to buy a shared smart product. In this Study, through the questionnaire survey, I prioritized 10 user needs. Under the price or function limit of the product, the design can give priority to some functions according to the most urgent needs of users, such as "easier to clean", "convenient", "time-saving", "comfortable", "easier to use".

#### 2.5. Study III: Understanding the bathroom cleaning context

#### 2.5.1. Research questions and 2.5.2. Results and analysis methods

Providing a technical solution for users to clean the bathroom is part of my initial objective. I need to theoretically understand the cleaning concerns by literature research and keywords internet search. Interview and questionnaire survey help understand real user's thoughts and the cause of dissatisfaction. My study question is:

> "What are needed to clean and how to clean?"

#### Dissatisfaction of users

Comparison of two types of dissatisfaction It is a normal case that people share a private bathroom with family members or tenant sharers. The multi-use of bathroom by multiple people causes inconvenience for one another. This inconvenience can lead to dissatisfaction. The dissatisfaction to sharers can be divided into two groups: using behavior dissatisfaction and cleaning habit dissatisfaction.

Are you satisfied with your bathroom sharers' .....? (i) Using behavior, (ii) Cleaning habit



Chart 2.5.2-1: Comparison of dissatisfaction of using and cleaning habits.

Respondents answered the question "Are you satisfied with your bathroom sharers' ((i) Using behavior, (ii) Cleaning habit)?". Obviously, among the 51 respondents, dissatisfaction with cleaning habit is more than dissatisfaction with usage behavior (17:6) (see Chart 2.5.2-1). In self-written answers to the further questionnaire, only 2 respondents gave specific examples of dissatisfied usage behavior, such as forgetting to change paper roll. On the contrary, for cleaning habits dissatisfaction, whether on the Internet or in interviews, people can give a long list of examples without thinking, such as the drain covered by hair, the dirt residue in the sink, etc. Therefore, dissatisfaction with the cleaning habits of the sharers is a dominant factor in terms of dissatisfaction with the bathroom.

#### Influencing factors of the cleaning habit dissatisfaction

Regarding the influence of gender and number of sharers on dissatisfaction, I have the following two findings:

- Among the 51 people, the dissatisfaction with cleaning habits has the highest proportion of same-sex shared bathrooms (38.8%), followed by family bathrooms (26.3%), and finally mixedsex bathrooms (23.5%). Contrary to what I suspect, homosexuality is more likely to cause dissatisfaction.
- When the number of sharers is particularly small (e.g., 1) or particularly large (e.g., 8), users are more likely to have dissatisfaction with other people's cleaning habits. The specific statistics are shown in the following table 2.5.2-1:

Table 2.5.2-1: Dissatisfaction percentage of cleaning	
habits of users with different number of sharers.	

Number of sharers	Number of dissatisfied users/all users	Dissatisfaction percentage
1	3/6	50%
2	4/16	25%
3	3/18	16.6%
4	1/6	16.6%
5	1/3	33.3%
8	2/2	100%

#### The time of dissatisfaction occurred

People use bathroom temporarily, so that dissatisfaction always occurred in the three time periods: (i) after using toilet, (ii) after bathing, (iii) when the bathroom is in great demand. When asked respondents when the in-bathroom experience of respondents was influenced by their sharers, about 50% mentioned "when the bathroom was in high demand", followed by "after he/she using toilet" (40%), and finally "after he/she bathing" (25%). (see Chart 2.5.2-2)

When do your sharers frustrate your in-bathroom experience? 51 responses



Chart 2.5.2-2: The results of the time when sharers frustrate user's in-bathroom experience.

With regard of the time when the bathroom is in great demand, the number of sharers and dissatisfaction are directly related (see Table 2.5.2-2). As the number of sharers increases, the user's bathroom experience is more likely to be affected by the large demand for the bathroom. Regardless of the lack of usage time, the cleaning time is greatly affected, such as insufficient deodorizing time.

Table 2.5.2-2: For users with different number of sharers, dissatisfaction percentage of when the bathroom is in great demand

Number of sharers	Number of dissatisfied users/all users	Dissatisfaction percentage of when the bathroom is in great demand
1	2/6	33.3%
2	7/16	43.7%
3	9/18	50%
4	4/6	66.7%
5	1/3	33.3%
8	1/2	50%

In a nutshell, for these three time periods, the generation of cleaning dissatisfaction can be classified into two categories:

- Insufficient cleaning time (when the bathroom is in great demand).
- Not clean or not clean enough (after using toilet; after bathing).

#### The treatment targeting dissatisfaction

How do users deal with this dissatisfaction? The questionnaire result shows that respondents mostly use 3 ways to deal with dissatisfaction (see Appendix D). Except for a small number of people who will communicate honestly, most people choose to endure silently or choose the most unbearable questions to communicate. This makes the dissatisfaction not resolved in time.

#### Hygiene problems

By clustering, I divided the hygiene problems of the bathroom into two groups: visible dirt and invisible dirt.

#### Visible dirt

Regarding the visible dirt, I collected a series of cases and sorted them out from the following three aspects. The table 2.5.2-3 shows typical examples.

Table	2.5.2-3:	Visible	dirt	classification	and	case
preser	ntation.					

Water	Gaseous	Steam after bathing.
	Liquid	Water on the ground after bathing. Fogged up mirror after bathing. Water splashed on the countertop after washing hands.
	Solid	Water scale on the wall.
Odor	Odor caused by the previous toilet usage.	
Dirt residue	Trash bin full of garbage. Drain covered by hair. Stubble in the sink.	



Figure 2.5.2: The place where invisible bacteria are produced

#### Invisible dirt

Invisible hygiene refers to bacterial contamination. The two interviewees mentioned in the interviews that they always wiped the toilet seat before using even though it looked clean. They subconsciously think that the toilets used by others are full of bacteria. One questionnaire respondent also pointed out this point. Through online research, I also found that many people have similar concerns. The Figure 2.5.2 shows the place where invisible bacteria are produced, such as sink drain, shower drain, toilet flush, etc (Rusin et al, 1998).

In order to understand the user's preference for automatic cleaning, I gave three options in the questionnaire: Fully automatic cleaning, Automatic cleaning + manual cleaning, Smart product giving recommendation + manual cleaning. About 54% of respondents prefer a combination of automatic cleaning and manual cleaning; about 33% of respondents prefer fully automatic cleaning; the rest prefer smart product to give advice and then manual cleaning. (see Chart 2.5.2-3). Respondents stated that fully automatic cleaning may not achieve the desired level of cleanliness and therefore requires manual cleaning.

Through literature research, I found that there are two ways to achieve automatic cleaning:

- Sensors control the switch of inbathroom appliances, which allows the appliance to complete its cleaning function. In the paper (Banait et al, 2019), an automatic bathroom cleaning system was proposed. Arduino UNO and three types of sensors, such as smell detector, were used to do automatic deodorizing, flushing and so on.
- 2. Automatic cleaning to ambient environment is done by a separate cleaning robot. In the paper (Prabakaran et al, 2018), A cleaning robot is generated with a Tetris structure. As the external environment changes, the robot can transform the shape to adapt to the environment in order to maximize the cleaning of the dirt.

#### Which of the following cleaning ways do you prefer?

51 responses



Chart 2.5.2-3: Preference of cleaning ways.



#### 2.5.3. Key takeaways

- When users are dissatisfied with sharers' cleaning habits, some users will hesitate to communicate with sharers, especially if they are unfamiliar with them.
- 2. When the bathroom in great demand, previous user cannot have sufficient time to clean the bathroom.
- 3. Subsequent users tend to be frustrated by previous bathing and toilet usage.
- Some users mentioned that they are worried about the invisible dirt (bacteria) on the toilet seat even if it looks clean. They always wipe the toilet seat before using.
- 5. Some users say that they do not fully trust fully automatic cleaning, and residual dirt needs to be manually cleaned.
- According to the investigation of existing products, the self-cleaning of the product is mostly achieved by the cleaning function of the product itself, such as automatic flushing of smart toilets; the cleaning of ambient environment (such as the floor) is mostly completed by a separate cleaning product (such as romba).

In terms of dissatisfaction with bathroom, users' dissatisfaction is mainly caused by cleaning habit of their sharers. These dissatisfaction always occurred in three time periods: (i) after using the toilet, (ii) after bathing, (iii) when the bathroom is in great demand. With regards to these three time periods, the generation of cleaning dissatisfaction can be classified into two categories:

Insufficient cleaning time (happened mostly when the bathroom is in great demand). Not clean or not clean enough (happened mostly after using the toilet, after bathing).

Besides visible dirt, some interviewees mentioned that they would subconsciously

doubt the cleanliness of the products used, such as toilet seats. They usually wipe the toilet seat before use, even if it looks clean, and they still feel that it is full of bacteria. Thereby technical solution of cleaning needs to take into account invisible dirt.

In terms of automatic cleaning, "maid" are able to be embedded into a smart appliances or exist as separated cleaning products. self-cleaning of the product/ appliance is usually done by sensor controlled cleaning function of the product/ appliances itself, such as automatically flushing toilet. Cleaning of the ambient environment is always done by a separate cleaning robot, such as automatically cleaning floor by romba.

#### 2.6. Study IV: Analysis of artifactual enablers

2.6.1. Research question and 2.6.2. Results and analysis methods

Towards a technical solution, the understanding of artifactual enablers is important. I need to theoretically understand existing intelligent system and its composition by literature research and keywords internet search. My study question is:

> "How to create a smart system?"

Targets of intelligent system

There are a wide variety of existing intelligent products. Four targets of intelligent system are proposed by Paulovich et al (2018).

- 1. Complete the automation inside the house. For example, a product of Nest can adjust the temperature in the room according to the user's previous choice. (Nest, 2019).
- 2. Supervise human physical data in sports activities. The article cites a series of smart products that monitor athletes' physical data. These data are used to identify athletes' weaknesses in order to improve the performance of the game (Paulovich et al, 2018).
- 3. Monitor physical health data and apply it to medical products.
- 4. Track where, when, and how the product is used. The paper mentions that this type of smart product is mostly used for logistics (Paulovich et al, 2018).

This project is to provide users with a technical solution for cleaning and to help users use the bathroom more conveniently. In this project, automation of objects and bathroom environment status tracking are two targets of the smart system in a technical solution.

The principles of Cyber-Physical System (CPS) is to realize the loop: from sensing, to reasoning, then to learning, finally to adapting (Horvath, I., & Gerritsen, B. H., 2012). Learning and adapting both are more relevant to the big data methodologies and algorithm, such as machine learning, natural language processing, data visualization, and other areas (Paulovich et al, 2018), and will not be the emphasis of this project.

Through intelligent systems, systems can make decisions based on received input, and these systems can also learn and adapt from previous interactions. Similarly, smart sensors can act on the environment and what they perceive, and not explicitly, smart systems can be built using non-smart sensors, as learning and tuning components can depend on other components in the system.

In this project, "sensing" refers to the detection of dirt. The way to sense is to place sensors of different functions at the target location. For example, ATP sensors can monitor bacteria on the surface of objects. "Reasoning" refers to the recognition of user behaviors and take actions for users. In a smart system, sensors are a key component. Data is collected through sensors. The types of sensors that are used for data collection can be classified into four categories: video, audio, wearable, and environmental (Thapliyal, 2018).

The sensor type used depends on the requirements of the smart home. Considering the privacy issues, video sensors would not be considered in this project. Audio technology has been used to detect user's typical in-bathroom activities, such as showering, urination, defecation, flushing, washing hands and brushing teeth (Chen et al, 2005).

Environmental and wearable sensors are the top choice for many smarthome environments, the obvious reason being that audio and video sensors compromise the privacy of the people being monitored (Thapliyal, 2018). However, the disadvantages of wearable sensors are obvious: (i) high price, (ii) the user must always wear it, which is not conducive to operation. Therefore, environmental sensors, such as infrared sensors, can be used as a substitute.

#### 2.6.3. Key takeaways

As mentioned at the outset, the main focus of this project is to help users clean the bathroom. Cleaning functions of the smart system can be divided into two groups: automatic cleaning and tracking cleanliness, which are able to achieve two targets of smart system: automation of objects and tracking status of products.

"Sensing" and "reasoning" of the principle of CPS will be explored in this project, since these two are more related with cleanliness recognition.

Since the paper has been proposed to successfully recognize the user's bathroom activity by sound, the audio sensors can be used as an alternative option. In addition, environmental sensors are relatively affordable and can be used to reduce costs.

#### 2.7. Study V: Interaction exploration

#### 2.7.1. Research questions and 2.7.2. Results and analysis methods

As various forms of smart products enter people's daily lives, the way people interact with objects is also subtly changing. The initiator of the action has evolved from being just a person to being more than just a person. Objects can also initiate actions. I need to theoretically scope how people interact with smart products and (smart) bathroom by literature research and keywords internet search. Questionnaire survey and interviews helped me explore what are users' preference towards interactions . So my study question is:

> "As the bathroom becomes more smart, how will the way of various in-bathroom interactions change?"

Interactions between human and smart products

There are 5 main ways to interact with smart bathroom products (Askar, N., 2018).

- 1. Voice commander. According to **Consumer Intelligence Research** Partners, 10.7 million U.S. Amazon customers have an Amazon Echo. With the popularity of Alexa/Echo, many companies have added Alexa/Echocontrol compatibility to their products.
- 2. Mobile phone. App control of bathroom products is also a major trend. Some companies have introduced App that gives users the possibility to remotely control products. Moreover, nearly 90 percent of Americans use their phones in the bathroom, according to a June 2015 Verizon Wireless survey of 6,000 individuals.
- 3. Touchscreen/buttons. It can be seen that many companies use touch screens or combination buttons to control the product, and the waterproof performance satisfies the wet environment of the bathroom.
- 4. Motion detectors. Through motion detection, smart products can actively complete some services. For example, TOTO's smart toilet can monitor whether the people falls. The demister mirror can be heated automatically.
- 5. Handheld device. Geberit company has introduced handheld remotes that can control smart products even outside the bathroom.

With regard of that five ways of interaction with smart products, questionnaire respondents have their preference and the result can be seen in Chart 2.7.2-1.

### Which of the following ways do you want to interact with the smart product?



Chart 2.7.2-1: Respondents' preference for ways to interact with smart products.

- About 43% and about 37% of respondents are favored by motion detection or by voice commands to control smart products respectively.
- About 30% of respondents are favored by buttons or by touch screens to control smart products.
- About 19% of respondents are favored by mobile device/App to control smart products.

Which of the following features would you like to add to future smart in-bathroom products?



Chart 2.7.2-2: Respondents' favorite features.

Interactions between human and bathroom & interaction between bathroom and smart products(maid)

Interactions among human, bathroom, and maid can be represented by smart bathroom features. I extracted some key features of smart bathroom from the article (Askar, N., 2018).

Interaction between human and bathroom:

- Precision temperature control
- Maintenance control (Give easy-toaddress maintenance advice by tracking usage)

Interaction between bathroom and smart products (maid):

- Intelligent controls (Make decisions for users)
- Hygiene inspection
- Dirt cleaning

Through the form of a questionnaire, I showed these features to 51 respondents to explore their favorite interaction with bathroom. The results can be seen in chart 2.7.2-2.

- The feature of dirt cleaning is favored by about 69% of respondents.
- The features of hygiene inspection and maintenance control are favored by more than 40% of respondents respectively.
- 27% of respondents need precision temperature control feature.
- One respondent mentioned the feature of monitoring water or energy use.

Interactions among human, bathroom, smart products (maid) can be represented by smart features. I prioritized interactions by questionnaire survey which provides a reference for the selection of smart product features (see Table 2.7.3).

Table 2.7.3: Prioritized features of smart products.

Type of interaction	Prioritized/Prefered features
Interaction between human and smart products	Motion detection, voice commands.
Interaction between human and bathroom	Maintenance control
Interaction between bathroom and smart products (maid)	Dirt cleaning, hygiene inspection
# 2.8. Study VI: Market analysis

# 2.8.1. Research questions and 2.8.2. Results and analysis methods

Not only users could affect the consumer market, but also the huge amount of bathroom-products launched by companies are also affecting the needs of users. I need to understand the current market trend by literature research and keywords internet search. On the other hand, users' attitudes towards smart products were gain by questionnaire survey and interview. My study question is:

> "What is the trend of the future consumer market?"

Company development focus

For the smart bathroom product market, the following companies have different priorities for future development (Askar, N., 2018). The table 2.8.2-1 lists the product development trends of several sanitary companies.

My finding is that multi-functionality and energy efficiency are the more common development focuses, and different companies have different priorities for the two. Many companies are beginning to add compatibility with the Amazon Alexa/Echo in their products.

Kohler	<ul> <li>Offer convenience and functionality to enrich users personalized experiences, making them easier, more comfortable and more enjoyable.</li> </ul>
Niagara	<ul> <li>Intentionally not use smartphone- or Alexa-compatible/controlled technology.</li> <li>Use easily and save water</li> </ul>
Zurn Industries	<ul> <li>Benefit contractors and installers as well as end users.</li> </ul>
Geberit	<ul> <li>Put maximum control right in the palm of hand (handheld device).</li> <li>Not use smartphone- or Alexa-compatible/controlled technology.</li> </ul>
Moen	<ul> <li>Use smartphone- or Alexa-compatible/controlled technology for providing users countless ways to create their ideal shower.</li> </ul>
MrSteam	<ul><li>Remotely control.</li><li>Minimize installation effort.</li></ul>
Chicago Faucets	<ul> <li>Reduce water consumption, save power and improve hygiene.</li> </ul>

Table 2.8.2-1: Product development trends of some famous companies

# Analysis of the reasons why consumers do not use smart bathroom products

Via questionnaire survey, I found that about 90% of the 51 people do not use any smart products. 5 respondents are using smart toilets, and 1/5 has a full set of smart facilities (smart toilet, smart shower head, smart deodorizing systems), and the rest 2/5 also use illuminated mirror or demister mirror. The article (Askar, N., 2018) also mentioned that the popularity of smart products is not high.

These respondents who do not currently use smart products give their considerations. I have summarized the following reasons:

- Feel that the product is not necessary (16/46).
- Expensive investment (6/46).
- Big investment but small benefits (3/46).
- Lack of understanding or experience of smart products (5/46).
- Concerned that smart products will be damaged in the humid environment of the bathroom (4/46).
- Concerned electric leakage (3/46).
- Added effort (3/46).
- The house is rented and do not want to invest money. It is hard to get involved all sharers to invest for it (3/46).
- Concerned that smart products will take up space (2/46).
- Concerned private information leakage (2/46).
- Do not like the experience of using smart toilets (2/46).

Some of these reasons which are dominant, such as large investment but minimal benefits, have also been supported in the Harper's book (2018).

# New trend: retrofit model

"Smart tech is still at the luxury level, but look for the technology to start to trickle down to mid-range price points," DiClerico says. "We're seeing that right now with smart toilet seats. It used to be available only on luxury toilets costing thousands of dollars, but you can now buy a retrofit model for a couple hundred bucks." (Askar, N., 2018)

Many companies have noticed users' concerns about investment. Coupled with the fact that young people are now choosing to rent, users are becoming more cautious about investing in smart bathroom products. Some companies, such as Kohler, have introduced retrofit model products. These products are compatible with traditional bathroom products, are easier to install, and are significantly less expensive at the sacrifice of some features.

In the questionnaire, I intent to compare the user's acceptance of high-end smart products and retrofit smart products (see figure 2.8.2). For Kohler's these two products, 55% of respondents chose the second one, which is affordable and detachable. The Table 2.8.2-2 shows the reasons behind the respondent's choice, respectively. I found that tenants are more likely to choose a retrofit model which are more affordable in a rental environment.



1. Kohler's Numi intelligent toilet

Advantage: Multi-functional Disadvantage: expensive



2. Kohler's a PureWarmth heated toilet seat

Advantage: affordable, detachable, retrofitting. Disadvantage: not much function

Figure 2.8.2: High-end smart products and retrofit smart products in the questionnaire.

Reasons for choosing the No.1 product	Reasons for choosing the No.2 product		
<ul> <li>Multi-functionality can better meet my needs (12/23).</li> <li>The quality looks more reliable (3/23).</li> <li>The appearance of the product is very attractive (3/23).</li> <li>Provide a better experience (3/23).</li> <li>Time-saving (1/23).</li> <li>Effort-saving (1/23).</li> </ul>	<ul> <li>Affordable price (7/28).</li> <li>Although the function is not much, it has already met the demand (7/28).</li> <li>There is no need for multifunctionality (4/28).</li> <li>The appearance of the product is very attractive (4/28).</li> <li>Affordable price for a shared appliance (3/28).</li> <li>It seems to be easier to install and disassemble (3/28).</li> <li>It seems to be easier to use (2/28).</li> <li>Compatibility to existing toilet (2/28).</li> </ul>		

Table 2.8	3.2-2: Reasc	ons behin	d the resp	condent's	choice

Product voice control is a trend in the development of smart products. Many companies have started to add compatibility with the Amazon Alexa/Echo in their products.

Smart bathroom products are not popular today, and I have got a list of reasons through the questionnaire survey. In addition to the user's belief that they do not need smart products in the bathroom, considering the manageability of the project, the technical solution could take into account these reasons:

- A large investment but minimal benefits.
- The house is rented and do not want to invest much money.
- Smart products will take up place.

Some companies, such as Kohler, have introduced retrofit model products. These products are compatible with traditional bathroom products, are easier to install, and are significantly less expensive at the sacrifice of some features. Tenants are more likely to choose a retrofit model which are more affordable in a rental environment.

# 2.9. Synthesis: Convergence of insights

# 2.9.1. Personas

I have summed up two personas, representing the family bathroom users and rental bathroom users. Through previous research, I have summarized the problems that users will encounter in a shared bathroom environment and reflect these typical problems through the personas (see Figure 2.9.1). Personas form the basis of the participant selection in the final design evaluation tests.

"Monday morning is so embarrassing!"



"My mother always forget to clean her hair!" As the evaluation test of product concepts progressed, I found that the family user group's need for cleaning is much lower than tenants user group. The reason is elaborated in Chapter 3.4.5. So for the final interaction concepts exploration, only the tenants as the final user group.

Name: Chen Jia Nationality: Chinese Age: 25 Gender: Male

He shares a bathroom with 3 same-sex sharers in a dormitory apartment.

Frustrations:

- He wipes the toilet seat before using the bathroom every time.
- The exhaust fan in the bathroom takes 5 minutes to remove the odor. Monday morning is sometimes very embarrassing.
- His landlord is not allowed to replace the appliances in the bathroom.
- He is worried that his roommates are not willing to spend huge amounts on smart bathroom products.

Name: Emin Nationality: Dutch Age: 25 Gender: Female

She shares a bathroom with her father and mother.

Frustrations:

- She always complains about the water mist on the bathroom glass.
- She is responsible for cleaning the scale of the walls, which is often too late to clean up.
- His mother always forgets to clean the hair on the drain.
- She hates reading the instructions for smart products.

Figure 2.9.1: Personas

# 2.9.2. Future bathroom vision

The future bathroom in this project is mainly to achieve two functions: automatic cleaning and tracking cleanliness status. In this way, the interaction between human, bathroom and smart products is realized. The Figure 2.9.2 shows the future bathroom vision.



Figure 2.9.2: Future bathroom vision

By analyzing the previous interviews, I summed up 4 user values which reflect what user needs by using a smart toilet product (see Chart 2.9.3). Corresponding quotes are shown below each user value. These 4 points will also be used as criteria for the evaluation of the interaction concepts.

Feeling trustful	Feeling controlable	Feeling intimate	Feeling convenient (function & installation)
(cleaning)	(operation & maintenance)	(device & smart)	
<ul> <li>I don't trust others cleaning habit. So I wipe the toilet seat before every usage.</li> <li>I am very busy in the morning. So I will be annoyed when I see the toilet is dirty!</li> <li>I am sleepy! I have no time to check if it is clean.</li> <li>She doesn't want to lean back on the toilet lid because she thought its dirty.</li> </ul>	I clearly understand what it does! I would rather choose a simple and useful one. Too much effort to maintain it with others.	Bathroom is a very intimate space. It looks warm and friendly! I use toilet on everyday morning. If I have a good experience, it means a good start of a day! I feel a little awkward and uncomfortable when using smart toilet! It might leak my private information.	Cannot directly see the convenience. I already have a toilet, so I'd rather retrofit it. The second one is easy to install!

Chart 2.9.3: User value.

# 2.10.1. Design requirements for product concept

# Recognition

- 1. Design needs to avoid using camera referring to privacy issue (see Chapter 2.6.2).
- 2. The product should have the ability to perceive dirt on the toilet seat.

## Cleaning

- 3. Design needs to automatically disinfect both visible and invisible dirt on the toilet seat (referring to interviews).
- The product should be considered "easier to clean" (referring to questionnaire research) by reducing the user's manual cleaning.

# Installation and initiation of use

- 5. The product should be considered "compatibility" of smart product to the original home (referring to questionnaire research and interviews).
- 6. Installation of the product should not involve complex piping and wiring work.

## Safety

- 7. The water repellency of the product needs to be considered (referring to interviews).
- 8. The product should report the problem in time when the system fails.

## Price

9. The consumer price should be between 50 and 100 euro (referring to interviews).

## Durability

- 10. The product requires a charging cable interface (referring to interviews).
- 11. The product should work properly in a room with humidity greater than 50% ( referring to Jesus, A., 2013).

# 2.10.2. Design requirements for interaction concepts

# Controllable

- 1. The user can operate the system without a product manual.
- 2. Users can monitor product maintenance.
- 3. When the product fails, the user can clearly know the cause of the problem.

#### Intimate

- 4. Products can help solve peak usage cleaning issues (i.e. odor caused by previous usage, dirt on the toilet seat).
- 5. The product helps the user to arrange the optimal grooming time.
- 6. Products can establish uniform cleaning standards and prompt users to correct unhygienic habits (Standing urinating).

## Convenient

- 7. The user does not need to manually clean the toilet before usage.
- 8. Users can know the use of the bathroom remotely.

## Trustful

9. The product needs to inform the user that the toilet seat is clean in the form of data.

This page is intentionally left blank.

# 3. Ideation and conceptualization

# 3.1. Introduction of ideation& conceptualization

One of the key points in the design phase is to choose a clear design direction of product concept. Through the analysis of the research phase, I found that the dirt generated (i) after using the toilet and (ii) after the bath will cause dissatisfaction of sharers (tenants) most. As a graduation project, my final design cannot cover both two scenes at the same time. So I will produce 3 product concepts, each of which will cover one scene ((i) or (ii) scene). Afterwards, final product concept direction could be determined according to product concepts user tests.

Another important point is to explore how smart products interact, including people and bathroom, people and smart products, bathroom and smart products. Through interaction exploration, the ways of interactions can be explored, such as how sharers (tenants) use bathroom together, how smart products identify human activities, and how smart products take clean actions. The interaction concepts of different smart levels will affect the user interaction mode. In the end, I will produce 3 interaction concepts (different smart levels) and evaluate the users (tenants)' attitudes toward smart products through interaction concepts user tests.

Briefly, the design phase is divided into two parts: product concepts generation and interaction concepts exploration.

# 3.2. Design goal

The design goal is to...

# (1) reduce user's effort when cleaning the bathroom and

(2) assist users in using the bathroom together by a technical solution.

# 3.3. Product concepts

# 3.3.1. Brainstorm

The design scenes are the bathroom (i) after using the toilet and (ii) after bathing. For these two scenes, my product concept generation mainly considers two points:

On the one hand, through previous research found that one of the reasons users do not use smart products is that the installation of large smart products is timeconsuming, labor-intensive (large wiring work), and expensive. It is even more prominent for the tenants. "Retrofitted" smart product is a trend in smart products market, which is easy to install, compatible, affordable. Thereby, one important point of brainstorming is to generate smart products, which are easy to retrofit in a rented home.

On the other hand, the cleaning functions should be reflected in product concepts. The dirt on the toilet lid and the dirt on the drain are the key issues in the above two scenes, so I will generate cleaning methods from the point of automatic cleaning.

With regard to these two points, I have produced some ideas. These ideas can be seen in Figure 3.3.1.



Figure 3.3.1: Brainstorm.

# 3.3.2. Introduction of product concepts generation

I divided the brainstorming ideas into three groups: one for the drain and two for the toilet (see Figure 3.3.2). After that, I produced 3 product concepts with more details based on these initial ideas. Next, I will detail the key features of each product concept.



Figure 3.3.2: Initial ideas of three product concepts.

# 3.3.3. Concept 1: Drain oriented (C86)

Concept 1 is aimed at the accumulated dirt in the drain during or after the shower. This smart drain helps users clean shower waste, such as hair (see Figure 3.3.3). The specific components are as follows:



Figure 3.3.3: Concept 1: Drain oriented (C86).

## Audio sensor:

The audio sensor is used to monitor the sound of the user's in-bathroom activities. When the system detects by sound that the user is taking a shower, the smart drain starts working.

## Embedded trash can of drain:

The smart drain serves as a smart trash can. It includes a cover that can be opened automatically, net pockets, and a net pocket storage box. When the user starts to bath, the cover automatically opens so as to let dirt flow into net pocket. After bathing, the cover closes automatically. Users only need to throw away the net pocket, which is automatically sealed. Furthermore, the product has the function of automatically changing the net pocket.

## Red light indicator:

When the garbage in the bag is accumulated to the extent that it needs to be thrown, the indicator light turns red. Mobile prompt:

When the user does not clean the net pocket in time, the user's mobile phone will receive a message prompt.

# oriented-1 (P37)

Concept 2 is a smart toilet seat. It helps users track the invisible hygiene of the toilet seat and do automatic disinfecting (see Figure 3.3.4). The specific components are as follows:



Figure 3.3.4: Concept 2: Toilet oriented-1 (P37)

## Ultraviolet sterilizer:

The toilet lid is automatically closed after each use, and the ultraviolet light immediately completes automatic sterilization.

## ATP sensor:

ATP sensor is embedded on the toilet seat to monitor the bacteria index of the surface. When the sensor detects bacterial growth on the toilet seat, it will automatically turn on UV disinfection.

## Mobile tracking and control:

The toilet seat is monitored by the system and the user can track the toilet hygiene on the phone. Users can also remotely control the UV disinfection through the mobile phone.

# 3.3.4. Concept 2: Toilet 3.3.5. Concept 3: Toilet oriented-2 (T49)

The concept 3 is also designed for the toilet cleaning (see Figure 3.3.5). This concept mainly explores how to clean the toilet seat. The specific components are as follows:



Figure 3.3.5: Concept 3: Toilet oriented-2 (T49)

# Separated Bluetooth vibration sensor:

The vibration sensor is placed separately on the flush handle, and the flushing water is used to judge that the user has just used the toilet. After that, the toilet lid automatically closes.

## Sanitizer sprayer:

After the toilet lid is closed, the sprayer slides along the track to complete the disinfection of the toilet seat.

## Light indicator:

On the toilet lid, the green light indicates that toilet seat has been sterilized, and the red light indicates that the sanitizer liquid is to be added. The user can visually see the disinfection of the toilet.

# 3.4. Evaluation of product concepts

# 3.4.1. The objective of evaluation 3.4.2. User test setup

These three product concepts were designed for two scenes: (i) after using the toilet, (ii) after bathing. One of the purposes of this evaluation is to select the final design scene. Secondly, the product concepts generation is mainly aimed at exploring the cleaning method. Through testing, I want to know what cleaning functions the user needs in a shared bathroom environment.

# Material

User test material contains conceptual sketches of three product concepts and user test forms (see Figure 3.4.2). Need to mention that. I numbered the three concepts as "C86", "P37", and "T49", respectively, to avoid participants having the pre-preferences due to the numbering order (e.g., 1, 2, 3 or A, B, C). This naming method was also used in the interaction concepts tests.

The user test form is divided into two parts: basic information part and score parts of 3 concepts. The user test form can be seen in Appendix E. The six criteria for evaluation are: (i)simple to use, (ii)trustworthy, (iii) convenient, (iv)predictable, (v)easier to clean, (vi)time-saving. Additionally, there are remark boxes for recording comments and suggestions. One example of the user test form can be seen in Appendix F.

Unfortunately, by evaluating in coach meeting, the six criteria are not accurate enough, so scoring is not considered in the subsequent analysis. However, the remarks and suggestions given by the users play an important role in the subsequent final product concept conceptualization.



Figure 3.4.2: Product concepts testing setup

# **Participants**

Yocco (2017) elaborates a method to calculate qualitative research sample size. I have two types of user groups: family bathroom users and rented bathroom users. According to the Qualitative Sample Size Formula (Yocco, V., 2017), I need at least 5 testers per user group.

Finally, I invited 10 participants to attend user test, aged between 22 and 25 years old, who have the experience of sharing a bathroom with others and meet the target user group of the project. These participants have different engineering backgrounds, so that they have a certain understanding of sensors and smart technologies. Therefore, they could evaluate 3 product concepts from a practical level.

## Procedure

In the test, I described each product concept to the participants in turn. Participants can ask questions at any time. After understanding the concepts, they rated the concepts from six criteria and think aloud. I need to record their feedback during the test. As a qualitative evaluation, I clustered and summarized the feedback and then achieved the final abalysis results.

# 3.4.3. Results

# **Concept 1: Drain oriented (C86)**

There are two main problems of Concept 1:

(i) The feasibility of the net pocket is low, such as the limited space of the water outlet, then how to store the net pocket and the net pocket will cause the drainage to be unsmooth;

(ii) The leakage problem will cause safety hazards, and the wiring work is also troublesome.

Detailed remarks can be seen in Figure 3.4.3-1.



Figure 3.4.3-1: Remarks of concept 1.

#### Remarks:

- Net pocket will cause water blockage if there is too much garbage in the net pocket.
- It is very troublesome to change the net pocket if it can not be changed automatically.
- Taking out the net bag by hand is very dirty.
- Audio sensors can cause privacy leaks.
- Electricity leakage problems.
- Charging issues will cause the piping work troublesome.
- The app information prompt is superfluous. If the water is blocked, the user will naturally know to replace the net bag.

In general, participants most favor this concept.

(i) From a viability point of view, this concept is easier to implement.

(ii) On the other hand, it mainly reflects cost issues such as UV lamps and ATP sensors are expensive.

Detailed remarks can be seen in Figure 3.4.3-2.

Participants mainly questioned about the vibration sensor for Concept 3:

(i) Use a vibration sensor to determine if the user is flushing, which can cause a large error.

(ii) The external sensor was inconvenient to implement.

Detailed remarks can be seen in Figure 3.4.3-3.



Figure 3.4.3-2: Remarks of concept 2.

#### Remarks:

- UV light(sterilizer) is expensive.
- ATP sensor is expensive.
- Real-time bacterial feedback is not needed very much. If there is ultraviolet disinfection, the user will want to sterilize first without using feedback before using the toilet seat.



#### Remarks:

- External sensors feel cumbersome to use.
- Vibration sensors are easy to cause errors.
- The design needs to consider a sanitizer container.

Figure 3.4.3-3: Remarks of concept 3.

Comparing with Concept 2 and 3, participants indicates the concept 1 is probably not viable to implement. For concepts 2 and 3, users indicate that they have their own merits.

In addition to participants' remarks and suggestions, I employed a technique "weighted objective" (Van Boeijen, et al., 2014) to quantify and rate concepts. The criteria refer to the design requirements. I score weight for each criterion by gut feeling regarding of evaluation results. The score for each concept can be seen in Chart 3.4.4 with the concept 2 (P37) as the best outcome. I extracted three key points toward final product concept generation and interaction concepts exploration. The detailed suggestions of participants for each concept can be seen in Appendix G.

- For the cleaning of the toilet seat, in addition to chemical cleaning (UV disinfection), the user also requires physical cleaning, such as wiping the toilet seat to achieve the purpose of removing visible dirt.
- Regarding the choice of sensors, the participants indicated that they prefer integrated sensors rather than separate ones. For example, an infrared sensor, embedded in toilet seat, can be used to identify user activity by detecting body temperature. Audio sensors involve privacy issues.
- The product can only target tenant user group. Because family users are more trustful in the cleaning habits of their family members. They always communicate frankly even if they have problems. Compared to tenants, they have little demand for toilet cleaning.

		And					
		C86		P37		T49	
	Weight	Score	Total	Score	Total	Score	Total
Recognition	30	6	180	9	270	6	180
Cleaning	25	5	125	7	175	6	150
Installation and initiation of use	20	1	20	6	120	5	100
Safety	10	1	10	5	50	5	50
Price	10	2	20	3	30	5	50
Durability	5	2	10	5	25	7	35
Total score	100		365		670		565

Chart 3.4.4: Weighted objectives with the concept 2 (P37) as the best outcome.

This page is intentionally left blank.

# 3.5. Final product concept

# 3.5.1. Final product concept

Based on the above analysis, the final product concept is aimed at the toilet seat cleaning after using the toilet. Taking into account the participants' remarks and suggestions, the final product concept will be generated on the basis of Concept 2.

The product's cleaning function consists of two parts: cleaning visible dirt and invisible dirt. After flushing, the toilet seat will be automatically wiped by wiping components. The product also performs automatic UV sterilization after wiping to disinfect bacteria. Visualized final product concept can be seen in Figure 3.5 with explanation.

The final product design embodies the physical part of the principles of cyberphysical system. The product concept is used to complete automatic cleaning after the smart system senses dirt. When cleaning the visible dirt, it mainly reflects how the smart system perceives the user behaviors, which is the trigger of automatic cleaning. This is the interaction between the system (product) and the user and the environment (the toilet seat). For invisible dirt, the system sterilizes the bacteria by monitoring the bacteria on the toilet seat, which is the interaction between the system (product) and the environment (the toilet seat).

Wiping the toilet seat along the tracks.

3

# Wiping components

The figure above describes how the wiping components (cleaning executor) clean the toilet seat & lid. There are 3 steps:

The pusher is lowered to hold down

the wiping paper.

(1) After starting cleaning, the nozzle first sprays the sanitizer;

(2) then the pusher is lowered and pressed against the wipes to slide along the tracks;

(3) The wipes will be directly pushed into the toilet bowel at the end of the tracks.

**UV Light** After wiping seat, it is used to disinfect the bacteria on the seat surface.

The nozzle sprays

sanitizer.

Sanitizer & wipes container They are used to put sanitizer and wipes.

Figure 3.5: Final product concept.

# 3.5.2. Validation

Recognition

- Design needs to avoid using camera referring to privacy issue (see Chapter 2.6.2).
- 2. The product should have the ability to perceive dirt on the toilet seat.

#### Cleaning

- 3. Design needs to automatically disinfect both visible and invisible dirt on the toilet seat (referring to interviews).
- 4. The product should be considered "easier to clean" (referring to questionnaire research) by reducing the user's manual cleaning.

Installation and initiation of use

- ✓ 5. The product should be considered "compatibility" of smart product to the original home (referring to questionnaire research and interviews).
- 6. Installation of the product should not involve complex piping and wiring work.

#### Safety

- 7. The water repellency of the product needs to be considered (referring to interviews).
- ✓ 8. The product should report the problem in time when the system fails.

#### Price

9. The consumer price should be between 50 and 100 euro (referring to interviews).

#### Durability

- 10. The product requires a charging cable interface (referring to interviews).
- X 11. The product should work properly in a room with humidity greater than 50% ( referring to Jesus, A., 2013).

Regarding the 1st item, the camera has to be used because the system needs to conduct Body Posture Analysis to predict whether the user wants to use the toilet. Taking into account privacy, an infrared camera is implemented, which can only capture the silhouette of the user.

Regarding the 6th item, the uncertainty is great. Because the screen is used in the interaction concepts, which can result in the need for a charging piping.

Regarding the 7th and 11th items, since the product concept still exists in the conceptual level, the actual waterproof test cannot be performed.

Regarding the 9th item, considering that the subsequent interaction concepts apply sensors and screens, the cost should be much higher than the range of 100 Euro.

Regarding the 10th item, due to project constraints, the actual charging problem was not considered.

# 3.5.3. Constraints

Due to lack of knowledge of mechanism and time constraints, it is impossible to refine the mechanical structure of the product cleaning components. So the final product concept is an idealized design. This concept is designed to reflect (i) the needs of users that smart products have the ability to clean both visible and invisible dirt, (ii) the main physical part (automatic cleaning) of the cyber-physical system. In actual production, the mechanical structure of the product will change probably.

# 3.6. Interaction concepts

# 3.6.1. Introduction

The smarter the system, the more things the system does, and the less the user does. I distinguish three interaction concepts based on different levels of smart. The Figure 3.6.1 briefly compares the proportion of behavior of system and user in the three concepts. Additional, there are some similar functions reflected in each concept. But the smarter the system, the more accurate the function. Each interaction concept with details are described in the following sections. Furthermore, interaction concepts are in line with cyber-physical system principles. The following elaboration puts the focus on the cyber part of the principles, and the physical part will be briefly described.



Figure 3.6.1: The proportion of behavior of systems and users in different interaction concepts.

# 3.6.2. Concept 1: High-level smart (T99)

# 3.6.2.1. Main functions description

Users have a smart toilet seat that helps them better coordinate the use of the bathroom. It consists of three parts: an App, a screen hanging outside the bathroom, and a screen inside the bathroom. I will mainly introduce the main functions of this concept.

# Automatically open the toilet lid



Screen outside (Face recognition)

The face recognition system can detect the identity of each user.

Embedded microphone and infrared camera are embadded in the smart toilet seat. They can be used to identify the user's behavior and predict the user's next behavior through machine learning.



The infrared camera can predict the user's tendency behavior by Body Posture Analysis and react in advance. The microphone is used to collect sound to determine the user's in-bathroom activities.

In the present concept, the two are combined for the system to make a pre-judgment (1) to open the toilet lid (2) to clean the toilet seat. In the future, the system can also connect with other smart products in the bathroom.



The user behavior judged by the system is displayed on the screen. Users can improve the accuracy of the pre-judgment by correcting the wrong judgment. Because of the face recognition, the user's behavior is associated with the user himself. Therefore, as the number of iterations increases, the system's pre-judgment for users will become more and more accurate.

# Coordinate peak usage



The smart system can also help coordinate usage conflicts of peak hours.

#### Before peak hour: Plan grooming time for users

First, the system can be bound to user's Google Calendar to analyze users' schedule, and through the analysis of previous peak hour usage data, prompt the specific user to use the toilet early if necessary by message. The system can determine users' accustomed grooming time by previous usage data. The system can remind users to use the bathroom in time during the peak hour. If the user does not use the bathroom at the time recommended by the system, the system will increase the accuracy of the recommendation through machine learning.



After usage: Inform optimal use time

time.

For a better experience, the system will also recommend subsequent users to wait for the best time to use. For example, leave enough ventilation

#### During peak hour: Inform waiting time

The face recognition system will identify the number of people waiting outside the bathroom and make a pre-judgment of the waiting time and inform the users outside the door. At the same time, users in the bathroom will be notified to speed up.



Screen outside

# Informing



Through the judgment	The microphone and	The smart syste	em When the system occur
of the odor sensor, the	pressure sensor are	e monitors the use	of errors, the screen will
screen will prompt the	used together to	supplements a	nd also prompt the user.
user to check if the	determine if the user is	prompts the user	to
toilet bowl is clean.	standing urinating. I	f replace them in tin	ne.
	so, the app will promp	t When a failure occurs	, it
	the user to change this	s will be notified in tir	ne
	behavior.	by app and scre inside.	en

3.6.2.2. The embodiment of cyber-physical system principles

# The embodiment of cyber part

Regarding the smart of the system, it should realize the iteration loop of cyber-physical system principles: sensing, reasoning, learning, adapting (Horvath, I., & Gerritsen, B. H., 2012). Two main iteration loops of this concept are elaborated as follows, the visualized iteration can be seen in Figure 3.6.2.2-1 and Figure 3.6.2.2-2.

The function of automatically opening the toilet lid reflects the iteration loop as follows:



Figure 3.6.2.2-1: Main iteration loop of Concept 1.

- Sensing: By various sensors, the system can identify the user's identity and monitor user's in-bathroom activities.
- Reasoning: Through body posture analysis and sound analysis, the system can predetermine whether the user is about to use the toilet, and open the toilet lid for the user according to the judgment result.
- Learning: When a pre-judgment error occurs, that is, when the user does not use the toilet as predicted by the system, the system will record this error judgment through machine learning.

 Adapting: Through continuous error recording and machine learning, the accuracy of the system's judgment for each user is gradually improved. The more users use, the higher the accuracy.

For another function of the system (coordinating peak usage), the way this loop is embodied is:



Figure 3.6.2.2-2: Main iteration loop of Concept 1.

- Sensing: 1. By various sensors, the system can identify the user's identity and monitor user's in-bathroom activities. 2. Through the app, the system detects the user's schedule.
- Reasoning: According to the user's schedule, the system will recommend the optimal grooming time. Reduce or avoid users' poor user experience due to peak usage.
- Learning: When a recommendation error occurs, that is, when the user did not use the bathroom during the recommended time, the system will record this error recommendation through machine learning.
- Adapting: Through continuous error recording and machine learning, the accuracy of the system's recommendation for each user is gradually improved. The more users use, the higher the accuracy.

As for how to iterate and make decisions within the system, the following diagram (see in Figure 3.6.2.2-3) visualizes the technical architecture flow of the main functions.



Interaction concept 1 Main functions technical architecture

# The embodiment of physical part

The technical components of Concept 1 can be seen in Figure 3.6.2.2-4. It reflects the physical part of the cyber-physical system, that is, what physical components are used to (i) perceive the environment and user behaviors, (ii) achieve the automation.



Interaction concept 1: High-level smart (Personalized interaction) Implementation Diagram

Figure 3.6.2.2-4: Implementation diagram of Concept 1.

Figure 3.6.2.2-3: Technical architecture of Concept 1.

# 3.6.3. Concept 2: Middle-level smart (P32)

# 3.6.3.1. Main functions description

Similar as Concept 1, it consists of three parts: an app, a screen hanging outside the bathroom, and a screen inside the bathroom. Some of the functions of Concept 2 are similar to Concept 1, so they are not repeated in the text. The main features that are different from Concept 1 will be introduced next.

# Automatically open the toilet lid



Because there is no facial recognition system, user behavior cannot be personally recorded in the system. The system's prediction of user trend behavior is based on the database of all users, so the accuracy will be lower than Concept 1.

Similarly as Concept 1, embedded microphone and infrared camera are embadded in the smart toilet seat. They can be used to identify the user's behavior and predict the user's next behavior through machine learning.

# Coordinate peak usage



The smart system can also help coordinate usage conflicts of peak hours. However, the accuracy of recommended grooming time is lower than Concept 1.

#### Before peak hour: Plan grooming time for users

Similarly as Concept 1, user can link Google Calendar in the App and set accustomed grooming time. Different from Concept 1, which system has each user's personal data, the accuracy of recommended grooming time cannot be iterated.

# 3.6.3.2. The embodiment of cyber-physical system principles

## The embodiment of cyber part

Regarding the smart of the system, it should realize the iteration loop of cyber-physical system principles: sensing, reasoning, learning, adapting (Horvath, I., & Gerritsen, B. H., 2012). Two main iteration loops of this concept are elaborated as follows, the visualized iteration can be seen in Figure 3.6.3.2-1.

The function of automatically opening the toilet lid reflects the iteration loop as follows:



Due to the lack of personalized data, the main iteration of the system focusing on the prejudgement of users' behavior. The prejudgement is based on the collective data of all users.

Figure 3.6.3.2-1: Main iteration loop of Concept 2.

- Sensing: By various sensors, the system can monitor users' in-bathroom activities.
- Reasoning: Through body posture analysis and sound analysis, the system can predetermine whether the user is about to use the toilet, and open the toilet lid for the user according to the judgment result.
- Learning: When a pre-judgment error occurs, that is, when the user does not use the toilet as predicted by the system, the system will record this error judgment through machine learning.
- Adapting: Through continuous error recording and machine learning, the accuracy of the system's judgment for all users is gradually improved. The more users use, the higher the accuracy.

As for how to iterate and make decisions within the system, the following diagram (see in Figure 3.6.3.2-2) visualizes the technical architecture flow of the main functions.



Interaction concept 2 Main functions technical architecture

Figure 3.6.3.2-2: Technical architecture of Concept 2.

#### The embodiment of physical part

The technical components of Concept 2 can be seen in Figure 3.6.3.2-3. It reflects the physical part of the cyber-physical system, that is, what physical components are used to (i) perceive the environment and user behaviors, (ii) achieve the automation.

Interaction concept 2: Middle-level smart (Collective interaction) Implementation Diagram



Figure 3.6.3.2-3: Implementation diagram of Concept 2.

# 3.6.4. Concept 3: Low-level smart (C54)

# 3.6.4.1. Main functions description

This concept only consists of two parts: a screen hanging outside the bathroom, and a screen inside the bathroom. The main features different from Concepts 1 and 2 will be introduced next.

# Open the toilet lid

Different from Concept 1 and 2, the user needs to wave over the toilet lid to control the toilet lid to open automatically.



# Coordinate peak usage

In the evening, the screen outside will display the estimated peak hour tomorrow to remind users to arrange grooming time in advance if necessary. Then users can communicate in person.



Screen outside
### 3.6.4.2. The embodiment of cyber-physical system principles

### The embodiment of cyber part

This concept is the least smart, and the internal iteration of the system is minimal. All decisions of the system depend on the user's personal operations. So in this concept will not reflect the iteration loop.

As for how to make decisions within the system, the following diagram (see in Figure 3.6.4.2-1) visualizes the technical architecture flow of the main functions



Interaction concept 3 Main functions technical architecture

Figure 3.6.4.2-1: Technical architecture of Concept 3.

### The embodiment of physical part

The technical components of Concept 3 can be seen in Figure 3.6.4.2-2. It reflects the physical part of the cyber-physical system, that is, what physical components are used to (i) perceive the environment and user behaviors, (ii) achieve the automation.



Interaction concept 3: Low-level smart

Figure 3.6.4.2-2: Implementation diagram of Concept 3.

### 3.6.5. Constraints

In these three interaction concept, I used microphone and infrared camera for perceiving user activities. Due to project limitations, I did not pay much attention to privacy issues. But if it is an actual product, privacy issues need to be carefully considered.

Some of the designs in the concepts are idealistic and theoretical. For example, regarding the bacterial sensor, through literature research, I found that this sensor is generally used for sophisticated medical testing and the installation is complex, so the sensor is low practical. Therefore, in the actual design, an alternative sensor should be found to solve these practical problems.

Regarding the iteration of the system, this involves big data and machine learning. Because of the lack of knowledge, interaction concepts only describe how the system iterates from a logical level. The specific coding is not involved. This page is intentionally left blank.

# 4. Evaluation of interaction concepts

### 4.1. The objective of 4.2. User test setup evaluation

Regarding these three interaction concepts, cleaning and peak usage are the design priorities. Different levels of smart will affect the smart services of these two features correspondingly. Through evaluation tests, I want to know:

- How do users view these three interaction concepts,
- How the smart levels of products influence interactions between users and smart products,
- Whether these two features are compatible with a shared bathroom in a rental environment,
- What are the reasons and considerations behind the user's choice of smart products.

### Material

With regard of the feedback gotten from Pilot Test with Chair and Mentor, I improved each interaction concept. User test material contains explanations of three product concepts (PowerPoint), demonstrative prototypes (hardware and software ), user test protocol (see Appendix H), and user test forms (see Figure 4.2-1). The hardware prototype is a scale-down product model. It consists Arduino electronics, which can intimate functions of final product concept. I also built (software) demos of each interaction concept by Marvel.

The user test form is divided into two parts: basic information part and score parts of 3 concepts. The user test form can be seen in Appendix I. The 4 criteria for evaluation are: (i)controllable, (ii)intimate, (iii)convenient, (iv)trustful, referring to the user value (see Chapter 2.9.3). Additionally, there are remark boxes for recording comments and suggestions.



Figure 4.2-1: Product concepts testing setup

### **Participants**

With regard of the product concepts evaluation results, I keep one type of user groups: rented bathroom users. According to the Qualitative Sample Size Formula (Yocco, V., 2017), I need at least 5 testers per user group.

Finally, I invited 10 participants to attend user test, aged between 22 and 25 years

old, who have the experience of sharing a bathroom with others and meet the target user group of the project. (see Figure 4.2-2)

### Procedure

In the test, I described each interaction concept to the participants in turn. Participants can ask questions at any time. After That, participants need to experience the concept via demos. After understanding the concepts, they rated the concepts and think aloud. I need to record their feedback during the test. In the end, for the final qualitative analysis, I take two types of results into account: scores and verbal feedback.



Figure 4.2-2: Participants of interaction concepts test.

### 4.3. Results

For each concept, I clustered remarks and suggestions into 6 groups according to main functions of interaction concepts. I merged some similar remarks and the final results are as follows. All records of comments are detailed in the appendix J.

### 4.3.1 Concept 1: High-level smart (T99)

### 4.3.1.1 Evaluation results

Functions Negative feedback		Positive feedback
Opening toilet lid related functions	• Users have a feeling that they are monitored.	
Self-cleaning related functions	<ul> <li>It is enough to let user know that the toilet has been cleaned. They don't need to see data of the bacterial index.</li> </ul>	<ul> <li>It is good to see data.</li> <li>It can reduce user's cleaning burden, which is good.</li> </ul>
Bad usage prompting related functions	<ul> <li>Feedback feature is not necessary. It's good to communicate in person instead of by an anonymous message.</li> <li>Points not considered: what if users all do not confirm.</li> <li>Points not considered: what if the user has not changed the bad habits.</li> </ul>	• The system tells everyone bad habits that are good. Everyone has different standards for cleanliness, so having a system is equivalent to having a unified standard that reduces conflicts.
Replenishing related functions		• The "contribution analysis" feature is good. Users can jointly monitor the maintenance of the toilet.
Peak hour related functions	<ul> <li>Points not considered: what if the user outside the door is in a hurry to use the bathroom.</li> <li>If the user knows someone is waiting in line, he/she will feel pressure.</li> <li>Sending messages is not a good way to remind users that the toilet is available now. Similar to the bathroom inside the aircraft, there is a reminder light outside the door telling everyone if it is available.</li> </ul>	
Overall functions/ interface/ interactions	<ul> <li>Intimacy is low because there are too many interactive interfaces. Many things can be communicated face to face between users.</li> <li>It is not very convenient to use, because you have to learn how to use it.</li> <li>Points not considered: What if the user does not have facial recognition and goes directly to the bathroom.</li> <li>Points not considered: what if there is a guest using the toilet.</li> <li>The system is so smart (collecting too much information) that it makes me feel not intimate.</li> </ul>	<ul> <li>Because identity and behavior correspond, some information can only be seen by user himself/herself.</li> <li>Face recognition is more convenient.</li> <li>It is intimate. "I feel that it is like an assistant. It knows my habits."</li> </ul>

Since concept 1 and 2 have the similar average and mode results (see Table 4.3.1.2-1 and Table 4.3.2.2), the comparative analysis will be discussed together in Chapter 4.3.2.2. Here we only discuss the scoring of participants for each criterion.

Table 4.3.1.2-1: The average and mode of ratings of Concept 1.

	Concept 1: T99						
Criteria	Controllable	ntrollable Intimate Convenient		Trustful			
	4	4	5	5			
	4	2	2	2			
	5	4	5	2			
	5	4	4	5			
Ten	3	2	4	3			
ratings	4	4	4	5			
U	2	2	4	2			
	4	1	3	4			
	2	5	4	5			
	5	4	4	4			
Average	3.8	3.2	3.9	3.7			
Mode	4	4	4	5			

From the scores of participants for each criterion, the scores have a tendency to polarize. For a certain criterion, such as criterion "Intimate", some participants gave 5 points, while others gave 2 points or even 1 point. This trend can be seen more clearly in Chart 4.3.1.2-2. The rating range is 1-5 points. Taking 3 points as the average score, I divided the score into 3 groups: 1-2 points; 3 points; 4-5 points. This will make the comparison more obvious. Through interviews. I learned that the participants' acceptance of smart products are different. Some users are extremely disliked with smart products, so his/her rating will be relatively low for a specific criterion.

Since Concept 1 and 2 have many similarities, similar suggestions are discussed together in Chapter 4.3.2.3. Only the recommendations for the type of collected data of Concept 1 are described here.

The biggest difference between this concept and Concept 2 is that it has a face recognition system, so the system can collect personalized information for each user. Some participants are positive because it allows them to get more personalized services, such as helping users plan their washing time. They also mentioned that when a user moves away, they can directly delete the user's personal data. In this way, the previous user's behavior data will not affect the accuracy of the system judgment.

Among the 10 participants, 4 participants liked concept 1 and 4 people liked the concept 2. Some participants prefer Concept 2, since it only collects collectivized information. These participants said that the activities in the bathroom were very private and they did not want the system to know who they were, which made them feel insecure. Therefore, collecting collectivized information is more acceptable to them.



Chart 4.3.1.2-2: The score distribution of Concept 1.

### 4.3.2. Concept 2: Middle-level smart (P32)

### 4.3.2.1. Evaluation results

Functions	Negative feedback	Positive feedback
Opening toilet lid related functions	<ul> <li>Users have a feeling that they are monitored.</li> <li>Users have no motivation to correct the judgement of their behavior on the screen.</li> </ul>	
Self-cleaning related functions	<ul> <li>Users want to see feedback after the toilet is cleaned.</li> <li>The "double check" feature does not require a voice prompt, just open the toilet lid.</li> </ul>	• It is good to see the amount of bacteria on the screen. Very data support.
Bad usage prompting related functions	<ul> <li>It would be annoyed to see mass messages on the App.</li> <li>The confirm function on the mobile phone, some users will have cheating behavior.</li> <li>The system judged user's bad habits and made him/her feel uncomfortable. There can be some gentle hints.</li> <li>It is not very useful to let users write feedback.</li> <li>Some habits, such as standing urinating. If everyone doesn't mind this behavior, then there is no need to classify it into bad habits.</li> </ul>	<ul> <li>It is good to reflect problems by system, reducing the embarrassment. I feel very close to the system.</li> </ul>
Replenishing related functions		• The "contribution analysis" function is good! It is data supporting who maintain it more.
Peak hour related functions	<ul> <li>Regarding the use of toilets during peak hours, it is good for users to communicate face to face.</li> <li>Users feel under pressure to see the countdown on the screen.</li> <li>Points not considered: what if someone outside the door is in a hurry to go to the toilet. An emergency can be set.</li> </ul>	<ul> <li>Users can check the overall peak period situation on the App, which is good.</li> <li>It is good to know that people are lining up.</li> <li>This is useful when the APP is connected to user's Calendar. The system can help to plan the peak usage.</li> <li>It is good to see if the toilet is available remotely.</li> </ul>
Overall functions/ interface/ interactions	<ul> <li>Too much screens.</li> <li>The system has been evaluating user's behavior and making they feel not intimate.</li> <li>Too much effort spent to learn how to use it.</li> </ul>	<ul> <li>Anonymous system makes the user feel more comfortable and more relaxed.</li> </ul>

Because Concept 2 differs from Concept 1 in that the types of collected user data are different (personalized [Concept 1] and collectivized [Concept 2]), the final result is compared with Concept 1. The mode scores of the concept 1 and 2 have the same result, so the average of the two is mainly compared (see Table 4.3.1.2-1 and Table 4.3.2.2).

Table 4.3.2.2: The average and mode of ratings of Concept 2.

Concept 2: P32						
Criteria	Controllable	Intimate	Convenient	Trustful		
	5	4	5	5		
	4	3	2	3		
	5	4	4	2		
	4	2	3	4		
Ten	3	2	3	3		
ratings	4	3	4	5		
Ŭ	3	2	3	3		
	4	3	4	4		
	2	4	4	5		
	5	4	4	5		
Average	3.9	3.1	3.6	3.9		
Mode	4	4	4	5		

Regarding scoring criteria "Controllable" and "Trustfull", the average scores were slightly higher than Concept 1. The participants stated that because Concept 2 is slightly less smart than Concept 1, it will let them subconsciously feel more in control of the product.

Since the concept 2 mainly collects collectivized data, the system cannot give specific services to specific users (for example, it cannot intelligently remind the user to use the bathroom early and iterate the accuracy of the system recommendation according to the actual behavior of the user). Therefore, due to the degree of personalization and the reduction of recommendation accuracy, users feel that the "intimacy" and "convenience" of the Concept 2 are lower than Concept 1. In order to improve the accuracy of the system to identify user behavior, users need to manually correct the system's misjudgment. Some participants said that this has increased their burden, and it is very annoying that the system always use voice to broadcast what users are doing.

Most participants don't like the function of writing feedback to their roommates. They think that if they encounter problems, everyone will communicate in person. Writing feedback will increase their burden, like social software instead of a bathroom product.

Regarding the function that the system has a uniform cleaning standard and monitor the users, some participants indicate that this does not apply to all users. Some problems are not a problem if all users don't mind. Participants expressed the hope that they could adjust their cleaning standards themselves. If it is completely determined by the system, users feel that they are controlled by the system.

In this concept, the system records the cleaning contribution of each user, such as the replacement of sanitizer. Some participants said they liked this feature very much. This is a shared environment where everyone has to contribute. This makes it easy to see everyone's efforts and is fair to all users.

Participants expressed a preference for the functionality of Concept 1 for peak usage. The system is able to recommend the best usage time for each user more personally. Some users indicate that the APP can be associated with their alarms. Users don't want the app to send messages. The way they want it is to check the usage of the bathroom through the app, referring the lights outside the toilet on the plane.

### 4.3.3. Concept 3: Low-level smart (C54)

### 4.3.3.1. Evaluation results

Functions	Negative feedback	Positive feedback
Opening toilet lid related functions		
Self-cleaning related functions		
Bad usage prompting related functions		
Replenishing related functions	<ul> <li>It's good to tell user that it is time to supplement items instantly in the bathroom. No need to send the user a message.</li> </ul>	
Peak hour related functions	<ul> <li>There can be a reservation function, so that everyone knows who will use the bathroom in advance tomorrow.</li> <li>Manually queuing is not convenient.</li> <li>Not very trusting the peak of the second day of the system forecast.</li> <li>Points not considered: what if I will not leave the bathroom when someone waiting outside.</li> </ul>	
Overall functions/ interface/ interactions	<ul> <li>Without the APP, users can't remotely check the usage of the bathroom during my free time.</li> <li>This reduces the face-to-face communication among sharers.</li> <li>Concept 2 is more like an assistant. This concept is more neutral and similar to tools.</li> </ul>	<ul> <li>It is easier to use it.</li> <li>Although the function is basic, it is satisfied both in cleaning and in the peak period.</li> <li>No APP is very good. The bathroom problems are all solved in the bathroom.</li> </ul>

Regarding the scoring criteria "Controllable" and "Trustful", it is obvious that the mode is higher than the average (see Table 4.3.3.2). Combined with user feedback, they generally believe that because the product is low-smart, all operations are based on people themselves instead of the system. As a result, users feel that all operations are more controllable, and they trust products as if they trust themselves. This is especially true for those who have low acceptance of smart products among participants.

The reduction in smart makes the product more like a tool than an assistant. "This product is very neutral and seems like a tool to me. Concept 2 is more like an assistant." Quotes from a participant. This is also reflected in the score, the average and the mode of the criteria "Intimate" are 3 (score range 1-5) in Table 4.3.3.2.

For criteria "Convenient", users with low acceptance of smart products are given higher scores (see Table 4.3.3.2). They believe that this product meets their needs to a certain extent (such as automatic cleaning of the toilet seat, peak hours reminders, etc.), but it will not affect their lives (for example, will not send messages to the phone). They feel that instant information is more convenient (because there is no APP, users will receive a system prompt message through the screen when using the bathroom only).

### 4.3.3.3. Key takeaways

For participants with low acceptance of smart products, they prefer Concept 3. They do not want the system to collect too much information from them and don't want the system to manipulate their lives. Concept 3 satisfies their needs to a certain extent ((i) Helps clean the toilet seat. (ii) Coordinates peak usage.), which is sufficient for them.

Regarding the peak usage, there is a feature that the system can forecast the next day's peak hour. Participants hope to have an appointment function. Users can reserve a specific usage time on the system to help the rest stagger the peak usage period.

Concept 3: C54					
Criteria	Controllable	Intimate	Convenient	Trustful	
	5	3	5	4	
	4	3	3	4	
	5	5	4	4	
	4	3	3	3	
Ten	2	3	3	3	
ratings	5	2	4	4	
· ·····g·	2	2	4	2	
	3	3	3	4	
	5	3	3	3	
	5	3	3	5	
Average	4	3	3.5	3.6	

3

3

Mode

5

Table 4.3.3.2: The average and mode of ratings of Concept 3.

### 4.4. Conclusion

Through testing, I found that as the level of product smart decreases, participants tend to give higher scores for criteria "controllable" and "trustfull". Through the interview, participants indicated that products with low smart were more like a tool, and they had a stronger sense of control, because the decision of the product mainly depends on the users themselves. Conversely, as the level of smart increases, scoring of criteria "intimate" and "convenient" will be relatively higher. Users implied that smart products are like assistants, understanding their preferences and behaviors, so they feel more intimate. Smarter products also mean more services for users, which is more convenient.

On the other hand, it is found that the user's own acceptance of smart products determines whether they want an "assistant" or a "tool." For participants with low acceptance, the smarter the products, the more they feel insecure. This is because (i) smart product will collect their personal information,(ii) product's self-iteration and smart services will bring them uncertainty. They think this will increase their burden. For participants with a high degree of acceptance, they are concerned with what personal data the product collects. For example, participants who chose Concept 2 as their favorite concept said that Concept 2 does not provide personalized services as Concept 1, but it does not collect personal information as much as Concept 1 does. They feel that Concept 2 will give them a sense of balance, which provides both smart services and makes them feel safe.

The above conclusion points to the future design of smart in-bathroom products. The user's acceptance of smart products affects whether they want an "assistant" or a "tool". Furthermore, smart products should fully consider the wishes of users. For example, some participants mentioned that they want to adjust the cleaning standards set by the system, so as to best fit their usage. For users with high acceptance of smart products, what kind of information/data is collected is their most concerned. They want to achieve a balance between smart services and personal data.

### 4.5. Validation

### 4.6. Constraints

Controllable

- The user can operate the system without a product manual.
- 2. Users can monitor product maintenance.
- ☑ 3. When the product fails, the user can clearly know the cause of the problem.

Intimate

- 4. Products can help solve peak usage cleaning issues (i.e. odor caused by previous usage, dirt on the toilet seat).
- ✓ 5. The product helps the user to arrange the optimal grooming time.
- 6. Products can establish uniform cleaning standards and prompt users to correct unhygienic habits (Standing urinating).

Convenient

- 7. The user does not need to manually clean the toilet before usage.
- 8. Users can know the use of the bathroom remotely.

Trustful

9. The product needs to inform the user that the toilet seat is clean in the form of data.

Regarding the 4th item, the system does not directly solve the problem of odor, but recommends the user's optimal use time.

Regarding the 8th item, the user cannot directly check whether the bathroom is available through the APP. Only during peak hours, the system will send a message to the user to indicate that the bathroom can be used. In the test, I used prototypes and videos to show the participants how the product cleaned the toilet seat. Participants cannot intuitively experience how the product works. This limits the user's experience with the cleaning function. This is also reflected in other functions. I explained to the participants how the internal (cyber) system of the product predicts the user's behavior so as to open the toilet lid for the user in advance, but the user cannot directly experience it.

Through testing, I found that participants' acceptance of smart products is unequal. My three interaction concepts are divided according to the degree of product smart, so participants' acceptance will affect their subjective judgment subconsciously. If there is an opportunity to improve this test, I will choose to divide the participants into two groups: high acceptance of smart products; low acceptance of smart products. Then compare the test results among the same type of users.

Since the three interaction concepts are smart products, some functions require the participants to experience the iterative process of the product after using it for a period of time. That is, the system gradually improves the accuracy of the service (for example, more accurate opening of the toilet lid in advance; more accurate recommendation of grooming time). But in the limitation of this graduation project, this kind of functionality that takes time to verify can not be well experienced. Users can only experience through my description, which limits the user experience. If there is a chance to improve the test, my suggestion is to provide the working product to the user for a period of time, so that the test results will more accurately reflect the user experience.

The above three points are the constraints I found in the test. If I have the opportunity to do more in-depth research, these three points can be applied to improve the rigor of the research results.

### Reference

Deschamps-Sonsino, A. (2018). Smarter homes: how technology will change your home life. Apress.

Askar, N. (2018, March 5). How smart tech is changing the bathroom. Plumbing & Mechanical. Retrieved Spring, 2019, from https://www.pmmag.com

Watson, R., Mukheibir, P., Falletta, J., & Fane, S. (2018). The bathroom of the future-prospects for information and control. Liu, A. & Mukheibir, P. (2018) Digital metering feedback and changes in water consumption – A review, Resources, Conservation and Recycling, vol. 134, pp. 136-148.

Chew I, Karunatilaka D, Pin Tan C & Kalavally V. (2017) Smart lighting: The way forward? Reviewing the past to shape the future, Energy and Buildings, vol. 149, pp. 180-191.

Borsos, A., Kokas, B., & Bachmann, B. (2019, February). Who Owns Our Future? How to Find a Home?. In IOP Conference Series: Materials Science and Engineering(Vol. 471, No. 7, p. 072043). IOP Publishing.

Thapliyal, H., Nath, R. K., & Mohanty, S. P. (2018). Smart home environment for mild cognitive impairment population: Solutions to improve care and quality of life. IEEE Consumer Electronics Magazine, 7(1), 68-76.

Rusin, P., Orosz-Coughlin, P. and Gerba, C. 1998, "Reduction of faecal coliform, coliform and heterotrophic plate count bacteria in the household kitchen and bathroom by disinfection with hypochlorite cleaners", in Journal of Applied Microbiology, Vol. 85, pp. 819-828

Paulovich, F. V., De Oliveira, M. C. F., & Oliveira Jr, O. N. (2018). A future with ubiquitous sensing and intelligent systems. ACS sensors, 3(8), 1433-1438.

Nest. (2019). Nest Thermostats | Keep You Comfortable and Help Save Energy. [online] Available at: https://nest.com/thermostats/ [Accessed 15 May 2019].

Freeman D (2015) Market Trends: The Five Phases that Smart Lighting Providers must address to be Successful in the Internet of Things, Gartner, https://www.gartner.com/ doc/3067420/markettrends-phases-smartlighting?srcId=1-2994690285, [Accessed 15 May 2019]

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

Chen, J., Kam, A. H., Zhang, J., Liu, N., & Shue, L. (2005, May). Bathroom activity monitoring based on sound. In International Conference on Pervasive Computing (pp. 47-61). Springer, Berlin, Heidelberg.

Banait, P., Kore, S., Shaikh, A., Marbate, R., Tayde, D., Katre, S., & Mahajan, A. (2019). Automatic Washroom Cleaning System.

Prabakaran, V., Elara, M. R., Pathmakumar, T., & Nansai, S. (2018). Floor cleaning robot with reconfigurable mechanism. Automation in Construction, 91, 155-165.

Harper, R. (2011). The connected home: The future of domestic life. London, UK:: Springer.

Yocco, V. (2017). Filling Up Your Tank, Or How To Justify User Research Sample Size And Data — Smashing Magazine. [online] Smashing Magazine. Available at: https:// www.smashingmagazine.com/2017/03/ user-research-sample-size-data/.

Jesus, A. (2013). Humidity in bathrooms. [online] Business.inquirer.net. Available at: https://business.inquirer.net/137493/ humidity-in-bathrooms.

Van Boeijen, A., Daalhuizen, J., van der Schoor, R., & Zijlstra, J. (2014). Delft design guide: Design strategies and methods.

## Appendix B: An example of contextmapping interview





# COMTEXTMAPPING: ONE DAY OF WEEKENDS



98

### **Appendix C: Questionnaire form**

Shared bathroom survey	2019/5/22 Shared bathroom survey 5. What is your gender? *
	Mark only one oval.
Shared bathroom survey	Female
Sinareu battinoonin Survey	Male
is done by Yu Wang from the TU Delft.	Other
Before you answer the questionnaire, I will briefly introduce my research context. It is often the case	6. What is the type of the used bathroom?*
that a private bathroom is used by multiple people one after another. Typical examples for shared	"Dormitory bathroom" refers to the bathroom in student apartments. "Apartment bathroom" refers
private bathrooms are, such as, dormitory bathrooms and family bathrooms. Your in-bathroom activities can be divided into two groups:	to the bathroom in your own rented house and the shareholders are not necessarily students.
Using bathroom to clean yourselves (e.g., bathing);     Graning bathroom to current our or allow subconvertures	
2. Cleaning bathroom to support own or others subsequent use. The questionnaire will ask questions from these two aspects.	Same-sex dormitory bathroom
My study is to find possibilities of the future smart bathroom service-product. Lyill collect your	Mix-sex dormitory bathroom
opinions from the present and future dimensions: present using, present cleaning, future using, and	Eamily bathroom
tuture cleaning.	Same-sex apartment bathroom
The questionnaire will take you approximately 10 minutes to complete. Your participation in this study is entirely voluntary but extremely important. You can withdraw at any time. You are fee to	Mix-sex apartment bathroom
study to entitlely bottlet extremely important. Too can willicitiaw at any time. Too are nee to ship any question.	Other:
We believe there are no risks associated with this research study; however, as with any online	
activity the risk of breach is always possible. Your answers will be stored confidentially. We will	7. How many people do you share the bathroom with? * Mark only one oval
minimize any lisks by academicany communicating the conected data only with my tatola.	$\bigcirc$ 1
Your answer will give me valuable information to proceed this research study, thank you very much.	
* Required	
1. Do you share a bathroom with others? *	
The bathroom refers to the one in your family, dormitory, or rented apartment, rather than a public bathroom	
Mark only one oval.	
) Yes	$\bigcirc$ '
No Stop filling out this form.	٣
	Brecont LICING and OLEANING bother and it attac
Basic information about you are a shared private-bathroom	Present USING and CLEANING bathroom situation
user	8. Are you satisfied with your bathroom shareholders'?*
	Using behavior, for example, whether to flush the toilet, whether to use the bathroom for too long,
2. When were you born? *	etc. Cleaning habit, for example, whether to clean the hair on the ground, whether to clean the water on the countertop, etc.
Example: December 15, 2012	Mark only one oval per row
	Very dissatisfied Dissatisfied Neutral Satisfied Very satisfied
3. What is your nationality? *	
	Cleaning habit
4. What is your occupation? *	
Mark only one oval.	
Student	
Student (do part-time work)	
Full-time work	
Starof lathros servey 9. When you are dissatisfied with your shareholder(s), will you communicate with him/her	2019/5/22 Shared bathrons survey 14. Please write a reason why you don't want to use smart in-bathroom products. *
Stared bathrows survey 9. When you are dissatisfied with your shareholder(s), will you communicate with him/her about this matter?	2018/5/22 Started hathrows server 14. Please write a reason why you don't want to use smart in-bathroom products. *
Stared betwee servey 9. When you are dissatisfied with your shareholder(s), will you communicate with him/her about his matter? - Creck all that apply Creck all that apply	2019/5/22 Shared batteron survey 14. Please write a reason why you don't want to use smart in-batteroom products. *
Stared lattrose survey 9. When you are dissatisfied with your shareholder(s), will you communicate with him/her about this matter? * Check all that apply.  Endure silently	2019/5/22 Shared bathroos survey 14. Please write a reason why you don't want to use smart in-bathroom products, *
Stared bathrow survey 9. When you are disatified with your shareholder(s), will you communicate with him/her about this matter/ + Check all hat apply.  Choose the most unbearable problem to communicate  Choose the most unbearable problem to communicate	2019/5/22 Stared battross survey 14. Please write a reason why you don't want to use smart in-bathroom products.*
Sured between servey  Sured between servey  Sured between servey  Creck all that apply.  Creck all that apply.  Creck the most unbearable problem to communicate  Fully honest communication	2019/5/22 Shared bathrows survey 14. Please write a reason why you don't want to use smart in-bathroom products.*
Stared batteries survey Stared batteries survey Source are dissatisfied with your shareholder(s), will you communicate with him/her about this matter?* Check all that apply: Choose the most unbearable problem to communicate Fully honest communication Rebetilion with behavior	2019/5/22 Shared hatbroos survey 14. Please write a reason why you don't want to use smart in-bathroom products. *
Stared backnows survey 9. When you are dissatiafied with your shareholder(s), will you communicate with him/her about this matter /* Check all that apply. Choose the most unbearable problem to communicate Choose the most unbearable problem to com	2019/5/22 Stard Instrom survey 14. Please write a reason why you don't want to use smart in-bathroom products.*
Stared between surver  9. When you are disatified with your shareholder(s), will you communicate with him/her about this matter?* Creck all that apply: Creck all that apply: Choose the most unbearable problem to communicate Choose the unbearable problem to communicate Choose the unbearable problem to communicate Choose the most unbearable probl	289/5/22 Stard before server  14. Please write a reason why you don't want to use smart in-bathroom products.*
Stard betwee servey  9. When you are dissatisfied with your shareholder(s), will you communicate with him/her about this matter?*  Check all that apply:  Check all that apply Checks the most unbearable problem to communicate Fully honest communication Check all that apply  10. When do you clean the bathroom?*  Check all that apply	2899/5/22 Started bathroom servery  14. Please write a reason why you don't want to use smart in-bathroom products.*
Stared between servey  Stared between servey  Subset of the apply:  Check all that apply:  Subset of the most unbearable problem to communicate  Fully honest communication  Rebetilion with behavior  Other:  Subset of the apply:  Check all that apply:	28/9/272 Barrel hatkness servey  14. Please write a reason why you don't want to use smart in-bathroom products.*
Stared between surver  When you are dissatiafied with your shareholder(s), will you communicate with him/her about this matter?* Check all that apply. Choose the most unbearable problem to communicate Choose the most unbearable problem to commun	2007/20 Survel server 14. Please write a reason why you don't want to use smart in-bathroom products.* 
Stard lathrow server  9. When you are disatified with your shareholder(s), will you communicate with him/her about this matter?*  Oneck all that apply.  Choose the most unbearable problem to communicate  Fully honest communication  Rebetilion with behavior  Other:  After using toilet  After bathing  After using toilet  After using toilet	2195/22 Stared balances servey  1. Please write a reason why you don't want to use smart in-bathroom products.*
Stard between server  9. When you are diseatisfied with your shareholder(s), will you communicate with him/her about his matter?*  Check all hat apply:  Chock all hat apply:  Debellion with behavior  Other:  19. When do you clean the bathroom?*  Check all that apply:  All the using tolet  All washing hands  Debellion telestein debits use his use his	2895/28 Sared bathroom servey  1. Please write a reason why you don't want to use smart in-bathroom products.*
Stared bataneas survey  When you are dissatified with your shareholder(s), will you communicate with him/her about this matter?*  Check all that apply:  Choose the most unbearable problem to communicate  Pully honest communication  Rebeilding with behavior  Other:  10. When do you clean the batthroom?*  Check all that apply:  Alter using toilet  Alter using toile	2002/20 Stard to the server
Stared between surver  9. When you are disatified with your shareholder(s), will you communicate with him/her about this matter ?* Check all that apply: Choose the most unbearable problem to communicate Choose the data popy. Cho	21272 Stard servery
Stard between surver  9. When you are disastified with your shareholder(s), will you communicate with him/her about his matter?*  Creck all hat apply:  Chock all hat apply:  Chock all that apply:  After bathroom?*  Creck all that apply:  After subming indist  Regular cleaning (daily, weekly, monthly, etc.)  Other:  1. When do wour charabaldare faustrate you is bathroom areastions?*	289/22 Sared backware servey
Stared batanese surver  When you are dissatiafied with your shareholder(s), will you communicate with him/her about this matter?*  Check all that apply:  Dhere:  When do you clean the bathroom?*  Check all that apply:  After using toilet  After using toilet  Check all that apply:  1. When do your shareholders frustrate your in-bathroom experience?*  Check all apply:  1. When do your shareholders frustrate your in-bathroom experience?*  Check all apply:	2022 2022 2022 2022 2022 2022 2022 20
Stared between surver  Sured between surver  Sured between surver  Sured at that apply:  Check all that apply:  Choose the most unbearable problem to communicate Choose all that apply: Choose all that apply: Choose all that apply: Choose all that apply: Choose the most unbearable problem to communicate Choose all that apply: Choose the most unbearable problem to communicate Choose all that apply: Choose the most unbearable problem to communicate Choose all that apply: Choose the most unbearable problem to communicate Choose all that apply: Choose all that apply: Choose the most unbearable problem to communicate Choose all that apply: Choose the most unbearable problem to communicate Choose all that apply: Choose the most unbearable problem to communicate Choose all that apply: Choose the most unbearable problem to communicate Choose all that apply: Choose all that app	2007 terret server 2007 terret server terret server with a reason why you don't want to use smart in-bathroom products.* 2007 terret server server terret
Stard between surver  Sured between surver  Surved his matter?*  Creck all that apply:  Creck all that apply:  After bathing  Creck all that apply:  Creck all that apply:	
Stared batanese surver  When you are dissatiafied with your shareholder(s), will you communicate with him/her about this matter?*  Check all that apply:  Pully honest communication  Rebellion with behavior  Other:  Network all that apply:  After bathing  After washing hands  Regular cleaning (daily, weekly, monthly, etc.)  Other:  Network do your shareholders frustrate your in-bathroom experience?*  Check all that apply:  After heishe using toilet	2022 2022 2022 2022 2022 2022 2022 20
Stared batterion surver  When the batterion is in great demand When the batterion is in great demand When the batterion	<form></form>
Stared bakaness surver	<form></form>
Stared between weiver	<form></form>
Stard between surver	<form></form>
Stared between surver  When you are dissatiafied with your shareholder(s), will you communicate with him/her about this matter?*  Check all that apply.  I. When do you clean the bathroom?*  Check all that apply.  After using tolet After vashing hands Begulari cleaning (daiby, weekly, monthly, etc.)  Other:  1. When do your shareholders frustrate your in-bathroom experience?*  Check all that apply.  After he'she using tolet After he'she using tolet After he'she using tolet Check all that apply.  2. What h-isch bathroom related products do you use?*  Check all that apply.  2. What hi-sch bathroom related products do you use?*  Check all that apply.  3. When do is great demand  3. When do is great demand  4. When do is furget demand  5. Other:  4. When do is great demand  5. Other:  4. When do is great demand  5. Other:  4. When do is great demand  5. Other:  5. When is the thory on the is great demand  5. Other:  5. When is the apply.  5. Other:  5. Other	<form></form>
Stared batteries surver  When by our are dissatiafied with your shareholder(s), will you communicate with him/her check all that apply: Choose the most unbaarable problem to communicate Choose all that apply: Check all that	<form><text></text></form>
Stard before server  9. When you are disatified with your shareholder(s), will you communicate with him/her check all that apply:	<form><text></text></form>
Stared between surver  When you are dissatiafied with your shareholder(s), will you communicate with him/her  Check all that apply.  Choose the most unbearable problem to communicate  Choose all that apply.  After varing tolet  After varing tolet  After harsholders frustrate your in-bathroom experience?*  Chock all that apply.  After harsholders frustrate your in-bathroom experience?*  Choose all that apply.  Shart hi-ach bathroom related products do you use?*  Choose all that apply.  Shart tolet  Shart tolet  Choose all that apply.  Choose all that apply.  Shart hi-ach bathroom related products do you use?*  Choose all that apply.  Shart tolet  Choose all that apply.  Choose all that a	<form><text></text></form>
Stard between server   Sured between server  Sured art hat apple:  Chock all that apple:  Differ:  Chock all that apple:  Chock all that apple:  After using toilet  After using toilet  After using toilet  After using toilet  After heishe tarting  Chock:  Sured art hat apple:  Sured ar	<form><text></text></form>
Stard between weiver	<form><text></text></form>
Stard before server  9. When you are disatified with your shareholder(s), will you communicate with him/her check all that apply: Ch	<form><text></text></form>
Stard between server   Surved his matter?*  Creck all that appl:  Credit the all that appl:  Credit that appl:  Credit the all that appl:  Credit that a	<form><text></text></form>
Stard hatman surver   Sured hatman surver   Surved at that apply:  Check all that apply: Choose the most unbearable problem to communicate Choose all that apply: Check all tha	<form><text></text></form>
Stard before server  9. When you are disatified with your shareholder(s), will you communicate with him/her  Creck all that apply:  Creck all that apply:	<form><text></text></form>
Start backnow surve         9. When you are disatilified with your shareholder(s), will you communicate with him/her about this matter?*         Check all that apply:         Choose the most communication         Peeblino with behavior         Check all that apply:         After vashing hands         Regular cleaning (daily, weekly, monthly, etc.)         Check all that apply:         After heishe bathing         When to bathroom related products do you use?*         Check all that apply:         Mather bathroom related products do you use?*         Smart tolett         Imminated mirror         Smart tolett         Mobile App         Mobile App         Mobile App         Check all that apply:         The check all that apply:         Mather bathroom related products do you use?*         Smart tolett         Smart tolett	<form><text></text></form>
Stard backnow server  Subscription: Stard backnow server  Subscription: Stard a tappl: Subscription with backnow selected problem to communicate with him/her subscription with backnow Subscription with backnow Subscription with backnow Subscription with backnow Subscription Su	<form><text></text></form>
Start hubble action system/appliance         Other:         19. When do your chart holder for with your abareholder (b, will you communicate with him/her abarbane)         Other:         19. When do you clean the bathroom?*         Other:         10. When do your clean the bathroom?*         Other:         19. When do your clean the bathroom?*         Other:         10. When do your clean the bathroom?*         Other:         10. When do your charbholders frustrate your in-bathroom experience?*         Other:         10. When do your sharbholders frustrate your in-bathroom experience?*         Other:         11. When do your sharbholders frustrate your in-bathroom experience?*         Other:         12. When the bathroom is in great demand         Other:         13. Miror demister         Imministed minor         Imministed minor         Imministem show here bathroe         Other:         13. Wrou selected "Mobile App" option in the bathroe	<form><text></text></form>
Shore you are disatified with your shareholder(s), will you communicate with him/her additional the apply:         Check all that apply:         Choose the most unbearable problem to communicate         Choose the apply:         The abulto of the apply:         Choose all that apply:         Choose all t	<form><text></text></form>
Shere you are disatified with your shareholder(s), will you communicate with him/her shout this matter/?         Check all that apply:         Chellow silently         Choose the most communication         Chellow silently         Chellow difficiently apply:         Simatt oblewith         Chel	<form><text></text></form>

	Shared bathroom survey	2019/5/22 Shared bathroom survey
16. Which of the	following products do you prefer to buy? *	19. Which of the following cleaning ways do you prefer? *
Mark only one	oval.	Mark only one oval.
		Smart product giving recommendations + manual cleaning
1 2 4 1		Fully automatic cleaning
A STREET		Automatic cleaning + manual cleaning
1. 1992		Other:
1 Berle		
		20. Which of the following benefits do you want the smart product to bring to you? *
		Check all that apply.
		Convenient
		Time-saving
		Personalizing
C Kohler	's Numi intelligent toilet (Advantage: Multi-functional. Distadvantage: expensive)	Water-saving
		Energy-saving
		Easier to use
		Easier to cleaning
		Comfortable
		Enjoyable
		Safe
		Other:
C Kohler	s a PureWarmth heated toilet seat (Advantage: affordable, detachable, retrofitting.	
Distadvantage:	: not much function)	Powered by
17. Please use 1-	2 sentence to explain why you select that option in last question. *	Google roms
18. Which of the	following ways do you want to control the smart product? *	
Check all that	apply.	
By voice	command	
By butto	ns	
By touch	Iscreen	
By mobil	e device/App	
By motio	n detection	
Other:		

### **Appendix D: Insights of questionnaire research**



Dissatisfaction percentage of cleaning habits of users with different number of sharers:

Number of sharers	Number of dissatisfied users/all users	Dissatisfaction percentage
1	3/6	50%

2	4/16	25%
3	3/18	16.6%
4	1/6	16.6%
5	1/3	33.3%
8	2/2	100%

When the number of sharers is particularly small (e.g., 1) or particularly large (e.g., 8), users are more likely to have dissatisfaction with other people's cleaning habits.

#### Ways respondents deal with dissatisfaction

When you are dissatisfied with your shareholder(s), will you communicate with him/her about this matter?



Respondents are mainly divided into three ways to deal with dissatisfaction. In addition to frank communication, they always choose to silently endure or choose the most unbearable questions to communicate.

The time when respondents do cleaning

Dissatisfaction is an objective thing, and respondents have more or less poor experience in the three kinds of time periods mentioned in the questionnaire. 34 respondents shared the bathroom with 2-3 people which is the major group out of all respondents. I found that more people mentioned that they had a poor experience when the bathroom was in great demand, followed by the toilet after being used, and finally after bathing.

Table: for users with different number of sharers, dissatisfaction percentage of when the bathroom is in great demand

Number of sharers	Number of dissatisfied users/all users	Dissatisfaction percentage of when the bathroom is in great demand
1	2/6	33.3%
2	7/16	43.7%
3	9/18	50%
4	4/6	66.7%
5	1/3	33.3%
8	1/2	50%

As the number of sharers increases, the user's bathroom experience is more likely to be affected by the large demand for the bathroom

### When do your shareholders frustrate your in-bathroom experience?



When do you clean the bathroom?



- 67% of respondents have regular cleaning habits, such as daily, weekly, and so on. About 19% respondents do cleaning after bathing and about 27% respondents do cleaning after using toilet. The two interviewees mentioned in the questionnaire or interview that they wiped the toilet seat before using the toilet even though it looked clean. They subconsciously believe that the toilets used by others are full of bacteria.

The time when the respondent experienced a poor in-bathroom experience Abbreviation: W-When the bathroom is in great demand; AT-After using Toilet; AB-After Bathing. Table: for users with different number of sharers, when do their sharers frustrate their experience.

	w	AT	AB	AT+AB	AT+W	AB+W	AT+AB+ W
1 (6)	1	1		1	1		
2 (16)	6	4	4		1		
3 (18)	7	5	3		2		
4 (6)	3	1	1		1		
5 (3)	1	1	1				
8 (2)			1				1

- When asked when the in-bathroom experience of respondents was influenced by their sharers, about 50% mentioned when the bathroom was in high demand. Most of them have 2-3 sharers. As a subsequent user to the toilet, about 40% mentioned that they experienced poor experience. As a subsequent user to the shower, about 25% mentioned poor experience.
- Experience. Two people mentioned that when the roommate forgot to change the paper roll or was wet with her personal belongings, the experience would be poor.

Current situation of respondents using hi-tech in-bathroom products

- A shadowing of regionsmole damp meters in tradition products About 90% of the 51 people do not use any smart products. 5 people are using smart tollets, and 1/5 has a full set of smart facilities (smart tollet, smart shower head, smart deodorizing systems), and the rest 2/5 also use illuminated mirror or demister mirror.
- Reasons why respondents do not use hi-tech in-bathroom products

- Dres why respondents do not use In-tech In-bathroom products Feel that the product is not necessary (16/51). Feel that the product is not necessary (16/51). Expensive investment (6/51). Big investment but small benefits (3/51). Lack of understanding or experience of smart products (5/51) Concerned that smart products will be damaged in the humid environment of the bathroom (4/51).

- bathroom (4/51). Concerned electric leakage (3/51). Added effort (3/51). The house is rented and do not want to invest money. It is hard to get involved all shares to invest for 1 (3/51). Concerned private information leakage (2/51). Concerned private information leakage (2/51). Do not like the experience of using smart toilets (2/51).

Respondents' favorite using features

#### Which of the following features would you like to add to future smart in-bathroom products?





- The feature of dirt cleaning is favored by about 69% of respondents.
   The features of hygiene inspection and maintenance control are favored by more than
   40% of respondents respectively.
   27% of respondents reade precision temperature control feature.
   One respondent mentioned the feature of monitoring water or energy use.

#### Comparison of two products of Kohler

Which of the following products do you prefer to buy?



### 

- For Kohler's two products, 55% of respondents chose the second product, which is affordable and detachable.
   Reason for choosing the first product:

   Multi-functionality can better meet my needs (12/23).
   The quality looks more reliable (3/23).

# Provide a better experience (3/23). Time-saving (1/23). Effort-saving (1/23). Effort-saving (1/23). Affordable price (7/28). Affordable price (7/28). There is no need for multifunctionality (4/28). There is no need for multifunctionality (4/28). There is no need for multifunctionality (4/28). The appearance of the product is very attractive (4/28). Affordable price for a shared appliance (3/28). It seems to be easier to use (2/28). Compatibility to existing toilet (2/28).

The appearance of the product is very attractive (3/23). Provide a better experience (3/23).

#### Respondents' preference for ways to interact with/control smart products.

Which of the following ways do you want to control the smart product?

- Byvs 19 (37.3%) -17 (33.3%) Bybut





- About 43% and about 37% of respondents are favored by motion detection or by voice commands to control smart products respectively. About 30% of respondents are favored by buttons or by touch screens to control smart products. About 19% of respondents are favored by mobile device/App to control smart products.

Respondents favorite cleaning ways

Which of the following cleaning ways do you prefer?



atic cleaning + manual

About 53% of respondents prefer a combination of automatic cleaning and manual cleaning; about 33% of respondents prefer smart systems to give advice and then manual cleaning; the rest prefer fully automatic cleaning.

Benefits that respondents want to get from smart products

Which of the following benefits do you want the smart product to bring to you?



Easier cleaning and more convenient use of the bathroom were needed by 80% and 75% of respondents, respectively. "Time-saving" and "comfortable" have also met the needs of around 60% of respondents.

- "Water-saving" and "simpler use" have also met the needs of about 50% of respondents.

# Appendix E: User test form of product concepts

I give permission to use the recording of this user test as anonymised illustrations during the project "Towards a smart bathroom maid".

Yes	No						
Name:							
Age:							
Gender:	Male	Female					
Do you share a bathroom with others?							

Yes	No

In front of you, you see the concept C86. Please rate the concept C86 on the following criteria seen below.



In front of you, you see the concept P37. Please rate the concept P37 on the following criteria seen below.

Simple to use	$\bigcirc$	$\bigcirc$	$\bigcirc$	$\bigcirc$	$\bigcirc$	Complicated to use
Trustworthy	$\bigcirc$	$\bigcirc$	$\bigcirc$	$\bigcirc$	$\bigcirc$	Unreliable
Convenient	$\bigcirc$	$\bigcirc$	$\bigcirc$	$\bigcirc$	$\bigcirc$	Inconvenient
Predictable	$\bigcirc$	$\bigcirc$	$\bigcirc$	$\bigcirc$	$\bigcirc$	Unpredictable
Easier to clean	$\bigcirc$	$\bigcirc$	$\bigcirc$	$\bigcirc$	$\bigcirc$	Aggravated cleaning burden
Time-saving	$\bigcirc$	$\bigcirc$	$\bigcirc$	$\bigcirc$	$\bigcirc$	Not time-saving

**Remarks:** 

In front of you, you see the concept T49. Please rate the concept T49 on the following criteria seen below.



### Appendix F: An example of user test form

### **User Test Form**

I give permission to use the recording of this user test as anonymised illustrations during the project "Towards a smart bathroom maid".

Yes	No					
Name:	Yingfei	≥hang		$^{\sim}$	A	8 _
Age:	24			A		
Gender:	Male	Fem	nale		MC	(A)
Do you sh	nare a bathi	room with	others?			
Ves	No				· · ·	
			and an Annual Dirandon and Alban Annual Sound and Annual Providence Sound and	ana kwa katon tite untumpi katoka untuk katoka k	na 40 a géner a construction de la décembra de la départation de California de	L'

In front of you, you see the concept C86. Please rate the concept C86 on the following criteria seen below.

Simple to use	$\bigcirc$	$\bigcirc$	$\bigcirc$	Q	$\bigcirc$	Complicated to use
Trustworthy	$\bigcirc$	$\bigcirc$	Q'	$\bigcirc$	$\bigcirc$	Unreliable
Convenient	$\bigcirc$	$\bigcirc$	$\bigcirc$	$\bigcirc$	$\bigcirc$	Inconvenient
Predictable	$\bigcirc$	$\bigcirc$	$\bigcirc$	O'	$\bigcirc$	Unpredictable
Easier to clean	$\bigcirc$	$\bigcirc$	9⁄	$\bigcirc$	$\bigcirc$	Aggravated cleaning burden
Time-saving	$\bigcirc$	$\bigcirc$	Q/	$\bigcirc$	$\bigcirc$	Not time-saving

In front of you, you see the concept P37. Please rate the concept P37 on the following criteria seen below.

Simple to use	$\bigcirc$	$\bigcirc$	$\bigcirc$	Q	$\bigcirc$	Complicated to use
Trustworthy	$\bigcirc$	$\bigcirc$	$\checkmark$	$\bigcirc$	$\bigcirc$	Unreliable
Convenient	$\bigcirc$	$\bigcirc$	$\bigcirc$	$\bigcirc'$	$\bigcirc$	Inconvenient
Predictable	9⁄	$\bigcirc$	$\bigcirc$	$\bigcirc$	$\bigcirc$	Unpredictable
Easier to clean	0	$\bigcirc$	$\checkmark$	$\bigcirc$	$\bigcirc$	Aggravated cleaning burden
Time-saving	$\bigcirc$	$Q^{\prime}$	$\bigcirc$	$\bigcirc$	$\bigcirc$	Not time-saving
Remarks:						

· 白叶海薮马辅盖 · UV tight is expensiven 定档 1 (Automatic repleasement toilet seat)

In front of you, you see the concept T49. Please rate the concept T49 on the following criteria seen below.

Simple to use	$\bigcirc$	$\bigcirc$	$\bigcirc$	Q/O	Complicated to use
Trustworthy	$\bigcirc$	$\bigcirc$	$\bigcirc$	Q/O	Unreliable
Convenient	$\bigcirc$	$\bigcirc$	$\bigcirc$	$Q \sim 0$	Inconvenient
Predictable	$\bigcirc$	$\bigcirc$	$\bigcirc$	0 0	Unpredictable
Easier to clean	$\bigcirc$	$\bigcirc$	0	$\Diamond' \circ$	Aggravated cleaning burden
Time-saving	$\bigcirc$	$\bigcirc$	$\bigcirc$		Not time-saving

pressure senser embeddel on the Seat. a set of sprayer is more dimable. . sanitizer collector . need to i wipe the senitiver

### **Appendix G: Remarks and suggestions**

### **Concept 1: Convenient (C86)**

Remarks:

- Net pocket will cause water blockage if there is too much garbage in the net pocket.
- It is very troublesome to change the net pocket if it can not be changed automatically.
- Audio sensors can cause privacy leaks.
- Electricity leakage problems.
- Taking out the net bag by hand is very dirty.
- Charging issues will cause the piping work troublesome.
- The app information prompt is superfluous. If the water is blocked, the user will naturally know to replace the net bag.

Suggestions:

- The red light can indicate that the sewer starts to block water. It is time to change net pocket.
- In addition to the net pocket being used, the design needs to consider where the net pockets are placed.
- The design needs to consider the next steps if the user has not replaced the net pocket.
- The design can consider popping the net pocket out of the drain.

### Concept 2: Predictable (P37)

Remarks:

- UV light(sterilizer) is expensive.
- ATP sensor is expensive.
- Real-time bacterial feedback is not needed very much. If there is ultraviolet disinfection, the user will want to sterilize first without using feedback before using the toilet seat.

Suggestions:

- A wiping function is required to physically remove (visible & invisible) dirt.
- Product price around 50 Euros is acceptable.
- The design can refer to the automatic replacement toilet seat.
- The user wants the toilet lid to open automatically before use or automatically open after cleaning.
- In order to reduce the cost caused by ATP sensors. The design can determine when cleaning is required by detecting the frequency of use of the toilet seat.

### Concept 3: Trushtful (T49)

Remarks:

- External sensors feel cumbersome to use.
- The design needs to consider a sanitizer container.
- Vibration sensors can cause errors.

Suggestions:

- An infrared sensor can be used to detect body temperature to determine if someone is using the toilet.
- The design can embed pressure and temperature sensors on the toilet seat.
- Add a wiping function to clean both visible and invisible dirt.
- Instead of a sliding sprayer, a series of sprayers can be placed on the toilet lid.
- Clean the toilet bowel as well.

### **Appendix H: User test protocol**

### [introduction text]

First of all welcome and thank you for taking the time to help us.

We would like to document the test for our own reference, is it okay if we film?

Today we will be testing three interaction concepts of smart toilet seat. First I will give you a little background information about the product and its use. Then I will ask you to fill in a form to gather some basic background information about you. Thereafter I will ask you to perform three tasks with the prototype. I will ask you to fill in a short questionnaire after the completion of the tasks, followed by a few questions about the test itself.

--- user test form part 1 top half

[Background information]

This smart toilet seat serves a shared private bathroom, a home or tenant environment. The product contains a device and a corresponding screen interface.

### [test introduction text]

We will now instruct you to perform a set of tasks with the design.

Please keep in mind that during this test you have the right to stop at any time or to ask for a break. Important to know is that we are testing the design and not you. Any difficulties you might experience are at fault of the design.

Your role is to be the role on the card, act like the character would normally do and to think out loud. My role is to observe you and I can clarify the task if necessary. Seeing as the purpose of this test is to evaluate the smartness and user value of the interaction concepts. Do you have any questions before we begin?

[Tasks]

- 1. Experience the hardware of the product concept.
- 2. Listen to the elaboration of each interaction concept and think aloud.
- 3. Experience the software of the interaction concepts.
- --- fill in the questionnaire

[Interview questions]

• Which concept do you prefer and why?

# Appendix I: User test form of interaction concepts SEL EST FORM

I give permission to use the recording of this user test as anonymised illustrations during the project "Towards a smart bathroom maid".

Yes No						
Name:						
Age:						
Gender: Male Female						
Do you share a bathroom with others?						
Yes No						
In front of you, you see the concept C54. Please rate the concept C54 on the following criteria seen below.						

Not controlable	$\bigcirc$	$\bigcirc$	$\bigcirc$	$\bigcirc$	$\bigcirc$	Very controlable
Not intimate	$\bigcirc$	$\bigcirc$	$\bigcirc$	$\bigcirc$	$\bigcirc$	Very intimate
Not convenient	$\bigcirc$	$\bigcirc$	$\bigcirc$	$\bigcirc$	$\bigcirc$	Very convenient
Not trustful	$\bigcirc$	$\bigcirc$	$\bigcirc$	$\bigcirc$	$\bigcirc$	Very trustful



In front of you, you see the concept P32. Please rate the concept P32 on the following criteria seen below.

Not controlable	$\bigcirc$	$\bigcirc$	$\bigcirc$	$\bigcirc$	$\bigcirc$	Very controlable
Not intimate	$\bigcirc$	$\bigcirc$	$\bigcirc$	$\bigcirc$	$\bigcirc$	Very intimate
Not convenient	$\bigcirc$	$\bigcirc$	$\bigcirc$	$\bigcirc$	$\bigcirc$	Very convenient
Not trustful	$\bigcirc$	$\bigcirc$	$\bigcirc$	$\bigcirc$	$\bigcirc$	Very trustful

### **Remarks:**



In front of you, you see the concept T99. Please rate the concept T99 on the following criteria seen below.

Not controlable	$\bigcirc$	$\bigcirc$	$\bigcirc$	$\bigcirc$	$\bigcirc$	Very controlable
Not intimate	$\bigcirc$	$\bigcirc$	$\bigcirc$	$\bigcirc$	$\bigcirc$	Very intimate
Not convenient	$\bigcirc$	$\bigcirc$	$\bigcirc$	$\bigcirc$	$\bigcirc$	Very convenient
Not trustful	$\bigcirc$	$\bigcirc$	$\bigcirc$	$\bigcirc$	$\bigcirc$	Very trustful



### **Appendix J: Comments of interaction concepts**

Interviewee 1: Yiwen zhang

Concept 1 (T99) comments:

- The feature of adjusting the progress bar myself makes me feel stressed.
- Although the infrared camera can only capture my silhouette, I still feel uncomfortable.
- I don't like this feature of writing feedback. Although it is anonymous, it is still possible to be guessed by others that I wrote it.
- Cleaning function I can see the data support, so I feel very trustful.

Concept 2 (P32) comments:

- Anonymous system makes me feel more comfortable and more relaxed.
- I don't like the screen inside and outside the door. I don't feel at home, it is more like a hospital.
- I usually play with my mobile phone when using the toilet, and I have a feeling of being monitored from time to time.
- I would be annoyed if the app kept pushing me news about other people's bad performance.

Concept 3 (C54) comments:

- The unsmart system makes me feel more controllable.
- Without the APP, I can't remotely check the usage of the bathroom during my free time.

### Best like: Concept 2 (P32)

• I don't have the big responsibility to iterate this system, but it also facilitates my life to some extent.

\_\_\_\_\_

Interviewee 2: Chong Yin

Concept 1 (T99) comments:

- I feel that feedback feature is not necessary. Unless the toilet is really dirty, I won't give feedback, but it's good to communicate in person instead of by an anonymous message.
- My morning wash time hopes to be linked to my mobile phone alarm instead of the calendar, for example 20 minutes after getting up.
- Points not considered: what if the user outside the door is in a hurry to use the bathroom.
- Intimacy is low because there are too many interactive interfaces. Many things can be communicated face to face between users.
- It is not very convenient to use, because you have to learn how to use it.
- Still questioning the accuracy of the system.

Concept 2 (P32) comments:

- My bad habits prompted by the system are only visible to me. It doesn't make sense. It doesn't prompt me to correct.
- I don't like this feature (register). This will put pressure on those who contribute less (rarely maintain the product). This is not a big problem. It is better for everyone to be conscious.
- I can check the overall peak period situation on my mobile phone, which is good.
- I don't feel strong intimacy. Regarding the use of toilets during peak hours, it is good for users to communicate face to face.

Concept 3 (C54) comments:

- Although the function is basic, it is satisfied both in cleaning and in the peak period.
- Communicating with my roommate through two screens makes me feel not very close.

### Best like: Concept 3 (C54)

• It is easier to use it.

Interviewee 3: Ruiqi Yang

Concept 2 (P32) comments:

- Both the infrared camera and the voice gave me a feeling of being monitored and it is creepy.
- The confirm function on the mobile phone, some users will have cheating behavior.
- The "contribution analysis" function is good! It is data supporting who maintain it more.
- It's good to set the usual usage time, but
  I don't want to connect to the calendar.
  In this case, the system will know my too
  many things, it is just a toilet system.
- I want to know remotely whether there is anyone in the bathroom.
- I don't want to see a lot of feedback on my app that doesn't have anything to do with me. It's more annoying to send it every day.
- I am very used to communicating with my roommates through the interface, especially when we are not very familiar with it, reducing the embarrassment. I feel very close to the system.
- Still questioning the accuracy of the system.
- Let me see people lining up, which is good.

Concept 1 (T99) comments:

- I don't want to touch the screen in the toilet. I suspect it is not clean.
- Points not considered: What if the user does not have facial recognition and goes directly to the bathroom.
- Feedback this feature, too social, very troublesome. If there is a serious problem, we can just communicate in person.
- The system tells everyone bad habits that are good. Everyone has different standards for cleanliness, so having a

system is equivalent to having a unified standard that reduces conflicts.

 When my usage data was linked to me, the information I received on the app was more personal.

Concept 3 (C54) comments:

- It's good to tell me when I need to supplement items. I did it when I was using the bathroom. No need to send me a message.
- There can be a reservation function, so that everyone knows who will use the bathroom in advance tomorrow.
- No APP is very good. The bathroom problems are all solved in the bathroom.

Best like: Concept 3 (C54)

- I won't be bothered at other times, which is good.
- Smart systems reduce the social interaction between people.
- "Contribution analysis" feature is good. Everyone can be clear what others did.

Interviewee 4: Yue Chen

Concept 2 (P32) comments:

- I feel that the intimacy is not very high. The system has been judging my behavior. It wants to control me.
- I feel that I have to spend a lot of energy to learn how to use it.
- The system asks me to correct its judgment by voice questioning, so as to self-itate. Occasionally, it can be accepted, otherwise it will be annoying.
- I want to see feedback after the toilet is cleaned.
- The "double check" feature does not require a voice prompt, just open the toilet lid.
- The system judged my bad habits and made me feel uncomfortable. There can be hints, but I hope to use a gentle word.
- At the peak of the morning, seeing the system countdown will put me under pressure. Just tell me that someone is

waiting outside the door.

Concept 3 (C54) comments:

- This system is very simple and makes me feel that I can control it.
- Concept 2 is more like an assistant. This concept is more neutral and similar to tools.
- I don't really like the queuing of this concept. Fingerprint landing is more convenient.

### Concept 1 (T99) comments:

 There is still a feeling of being monitored, but since some messages have only been pushed to me, I feel more personal and intimate.

Best like: Concept 1 (T99)

• It is more personalized.

\_\_\_\_\_

Interviewee 5: Yancheng Du

Concept 2 (P32) comments:

- I think it is a very simple matter to go to the bathroom without using the app. This concept will make me spend effort to learn how to use it.
- I hope it can give me a feedback after the toilet is cleaned. Or let me know before using it next time.

Concept 3 (C54) comments:

- The concept of the forecast for tomorrow's peak period may lead to the use of the toilet in advance for everyone on the second day.
- The toilet lid can be automatically opened and held after cleaning. This way everyone knows that the toilet is clean.

Concept 1 (T99) comments:

- Points not considered: what if there is a guest using the toilet.
- Points not considered: what if users all do not confirm.
- Face recognition is more convenient.

 Points not considered: what if the user has not changed the bad habits. I don't have the motivation to correct bad habits. Even the system often prompts me.

### Best like: Concept 1 (T99)

• This concept is more technological and more futuristic.

-----

Interviewee 6: Qianqian Zheng

Concept 3 (C54) comments:

- This reduces the face-to-face communication between me and my roommate. If I and my roommate are not familiar with one another, it will make us more unfamiliar. If we are intimate, there is no problem.
- I have doubts about the cleaning ability of this product.

Concept 2 (P32) comments:

- It is good to see the amount of bacteria on the screen. Very data support.
- This is useful when the APP is connected to my calendar. The system can help me plan and make me more calm during the peak period.
- There are hints during the peak period, which is good. I don't have to go to the bathroom to see if there is anyone.
- It is not very useful to let users write feedback.
- This concept can help me do something that makes me feel more intimate between people and the system.
- The system is able to analyze my behavior, which is too smart and makes me a little scared.

Concept 1 (T99) comments:

- Points not considered: what if there is a guest.
- Pushing messages is more accurate and makes me feel more private.
- Face recognition is great, linking users to behavior.

Best like: Concept 1 (T99)

- It is more private and more personal. If I log out, my data will not be left.
- The smart level of the system is very suitable.

Interviewee 8: Guo Chen

Interviewee 7: Xinhe Yao

Concept 1 (T99) comments:

- The system collected too much data from me, I don't know who will use it.
- I know that someone waiting outside the door will put me under pressure. And people outside the door won't wait, they may leave after a glance.
- The APP should not tell me by information when the bathroom is available. Similar to the bathroom inside the aircraft, there will be a reminder light outside the door telling me if there is anyone.
- User writing feedback is not necessary. If there is a problem, just communicate directly.
- The system is so smart that it makes me feel not intimate.

Concept 2 (P32) comments:

- This system does not collect too much personal information from me, making me feel more controllable.
- The system has been evaluating my behavior and making me feel not intimate.
- Some habits, such as standing urinating. If everyone doesn't mind this behavior, then there is no need to classify it into bad habits.
- Points not considered: what if someone outside the door is in a hurry to go to the toilet. An emergency can be set.

Concept 3 (C54) comments:

- Manually increasing the number of queues is very uncontrollable.
- Not very trusting the peak of the second day of the system forecast.

Best like: Concept 2 (P32)

Concept 1 (T99) comments:

- I feel that the system is very comprehensive, so I have a sense of control.
- If I know someone is waiting in line, I will feel pressure.
- The "contribution analysis" feature is good. We can jointly monitor the maintenance of the toilet.
- It is enough to let me know that the toilet has been cleaned. I don't need to see this data for the bacterial index.
- I have reduced the cleaning burden and I feel very good.
- I hope the system tells me when to clean the toilet.
- Because identity and behavior correspond, some information can only be seen by myself. This protects my privacy.

Concept 2 (P32) comments:

 When there is a problem with my behavior, the screen in the toilet will prompt me. Instant information protects my privacy.

Concept 3 (C54) comments:

- It is easier to use it.
- No APP is very good.
- Manual queuing is not good.

Best like: Concept 2 (P32)

• The level of intelligence is more appropriate.

Interviewee 9: Fan Sun

Concept 2 (P32) comments:

 The system is controlling me. It has been evaluating my behavior. Very
dominant.

Concept 1 (T99) comments:

 Because user behavior corresponds to identity, this reduces mass messaging. More personal and avoiding embarrassment.

Concept 3 (C54) comments:

- Points not considered: what if everyone uses the toilet in advance because of the forecast.
- I just need to know if there are people in the bathroom, no need to line up.

Best like: Concept 2 (P32)

• The system is not so personal but convenient.

-----

Interviewee 10: Xin Guo

Concept 1 (T99) comments:

• It is intimate. I feel that it is like an assistant. It knows my habits.

Concept 2 (P32) comments:

• It will not leak my privacy. Not personal. So it is more trustful.

Concept 3 (C54) comments:

- Manually queuing is not convenient.
- Points not considered: what if I will not leave the bathroom when someone waiting outside.
- The system is not smart, so I will not feel intimate with it.

Best like: Concept 1 (T99)

• It is more smart and convenient.





