

**A SYSTEMATIC APPROACH AND DESIGN GUIDELINES  
FOR THE DEVELOPMENT OF SMART BATHROOMS  
CONSIDERING THE SENIOR POPULATION**

by

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## Abstract

Around the world, populations are aging, and the life expectancy of the senior population is also increasing. At the same time, a large portion of the elderly prefer to stay at home, which is known as aging in place. However, inevitably, the elderly are suffering physical, sensory and cognitive limitations, which result in difficulties in their mobility, self-care and household activities. Among these difficulties, bathroom activities, such as bathing, showering and toileting, may be the most troublesome for the elderly who are aging in place. In other words, the elderly need assistance, from assistive products or persons, to accomplish bathroom activities. However, assistive products, particularly for the elderly in their bathrooms, are still limited and mainly include products such as grab bars, which cannot meet all the needs of the elderly.

Thanks to advantages in automation and communication, smart technology is one of the most promising solutions for aging in place. In a smart home, the elderly will be able to maintain their autonomy under the assistance from smart products, and can live independently as long as possible with the help of smart technology. However, it is undeniable that the elderly frequently have the lowest acceptance of new technology and products. In order to instruct designers to design a smart bathroom that (1) fits the elderly's needs, (2) is willing to be adopted by the elderly and (3) gives full play of the advantages of smart home technology, an approach and design guidelines will be proposed.

Before presenting the design guideline, this study will conduct a literature review, in which the characteristics of the elderly, challenges of using the existing bathroom, and smart home

technology will be comprehensively studied. After that, the guideline of smart bathroom design considering the elderly population will be introduced, as well as representative examples of the application of this guideline.

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## **Chapter 1**

### **Introduction**

#### **1.1 Problem Statement**

The aging population is now an issue globally, and life expectancy is also increasing steadily globally (United Nations, 2017). At the same time, most of people age more than 65 prefer to stay in their current home and community as they age, which is known as “Aging in Place” (AARP, 2014). Because of this trend, the home environment and living conditions of the aging are closely related to the quality of their life and crucial to their wellbeing and happiness. However, most homes are not well designed for aging in place, and therefore their living environment is not satisfactory.

Elderly people often suffer from physiological, sensory and cognitive degradations, which lead to difficulties in accomplishing daily activities such as toileting, bathing, eating, cleaning and shopping, which are named ADLs (Activity of Daily Living) and IADLs (Instrumental Activity of Daily Living). Among all ADLs and IADLs, toileting and bathing are the most problematic due to the elderly-unfriendly bathroom furniture and the limitation of the elder’s ability. More importantly, the elderly need assistance, from products or persons, to finish these bathroom activities. In the market, assistive products for bathrooms are still limited and mainly include grab bars, which cannot meet all of the needs of the elderly.

The smart home is no longer a new phenomenon, as there exists today a great number of smart home products. The revenue in smart home market has reached 71,629 million dollars in 2019, with a household penetration rate of 7.7% (Statista, n. d.). However, being regarded as less profitable, the senior market has been demoted as a secondary concern (Chambers, 2016, p. 166), particularly smart devices for elderly bathrooms. However, this demographic group needs

assistance the most, and smart home devices could be a great help. Therefore, this study will analyze problems that exist in elderly bathrooms, and provide an approach and design guidelines for designers who want to design smart bathroom devices for the elderly.

## **1.2 Need for Study**

Applying smart assistive products to help the elderly in the bathroom can be beneficial in various aspects.

First of all, the elderly's physiological and sensory limitations can be compensated for so that they can finish toileting, bathing, showering, grooming and cleaning independently, which will maintain healthy physical conditions. Further, being capable of accomplishing ADLs and IADLs will make them feel independent, which is vital for mental health, and they will be capable of living in their preferred environment as long as possible, instead of being forced to move into a nursing home.

In addition, the elderly rely on caregivers or other form of services to assist with ADLs and IADLs, which can be costly. With assistive tools, in the long term, the elder's expenditures on daily assistance can be reduced.

Furthermore, smart homes have numerous advantages in helping the elderly. Smart devices are adaptable and responsive, meaning they can fit the elderly's changing needs and respond according to different situations. Also, smart devices are connected to the Internet. In other words, the elderly's home can be connected to other stakeholders, families and professionals, increasing the efficiency and accuracy of communication among them.

### 1.3 Objectives of Study

This study will provide designers with a systematic approach and corresponding design guidelines about how to design a bathroom to assist the elderly in their activities within the smart home. Detailed objectives are listed as below:

- Research limitations of the elderly, which include physiological, sensory and cognitive limitations.
- Research what challenges the elderly face in the bathroom and other difficulties that are related.
- Research what kinds of assistance and products the elderly need in the bathroom.
- Research existing assistive bathroom products in the market.
- Research how to design smart devices to be user-friendly for elderly users.
- Research the acceptance and preference of smart home products and technology by the elderly.

### 1.4 Definition of Terms

**Activities of Daily Living (ADL)** - Activities of daily living, which includes self-care tasks such as bathing, showering, dressing and so on ("Activities of Daily Living," 2018).

**Age-related Macular Degeneration (AMD)** - Age-related macular degeneration (AMD) is the leading cause of blindness in the developed world. AMD is characterized by progressive destruction of the retina's central region (macula), causing central field visual loss (Klein et al., 2005).

**Aging in Place** - The ability to live in one's own home and community safely, independently, and comfortably, regardless of age, income, or ability level ("Health Places Terminology," 2009).

**Assistive Technology (AT)** - Assistive technology (AT) is an umbrella term. It refers to products, instruments, equipment or technologies specially designed for improving the functioning of a person with disability (Larsson & Östergren, 2011).

**Instrumental Activities of Daily Living (IADL)** - Instrumental activities of daily living (IADL) are activities related to independent living and include preparing meals, managing money, shopping for groceries or personal items, performing light or heavy housework, doing laundry, and using a telephone (Leon-Male & Rothkoff).

**Internet of Things (IoT)** - The Internet of things (IoT) is a term used to describe the network of devices such as home appliances that contain electronics, software, actuators, and connectivity which allows these things to connect, interact and exchange data ("Internet of Things," 2018).

**Mild Cognitive Impairment (MCI)** - Mild cognitive impairment (MCI) is defined as cognitive impairment in at least one aspect of cognitive functioning, with no sign of dementia and no significant decline in functional activities of daily life (Sixsmith, 2013).

**Perceived Ease of Use (PEOU)** - According to TAM, perceived ease of use (PEOU) is one of the factors that will influence user acceptance of technology (Davis, 1989).

**Perceived Usefulness (PU)** - According to TAM, perceived usefulness (PU) is one of the factors that will influence user acceptance of technology (Davis, 1989).

**Smart Devices** - A smart device is an electronic device, generally connected to other devices or networks via different wireless, that can operate to some extent interactively and autonomously ("Smart Devices," 2018).

**Smart Home** - Smart home is an application of ubiquitous computing that is able to provide user context-aware automated or assistive services in the form of ambient intelligence, remote home control or home automation (Alam, Reaz, & Ali, 2012).

**Technology Acceptance Model (TAM)** - Fred D. Davis' model of technology acceptance (Davis, 1989).

**Ubiquitous Computing (UbiComp)** - Ubiquitous computing (UbiComp) is a concept where computing is made to appear anytime and everywhere. In contrast to desktop computing, ubiquitous computing can occur using any device, in any location, and in any format. A user interacts with the computer, which can exist in many different forms, including laptop computers, tablets and terminals in everyday objects ("Ubiquitous computing," 2019).

## **1.5 Assumptions**

This thesis study includes several assumptions, which are listed as below:

- This study utilized a great number of materials such as books, thesis, dissertations and websites as references to support the research, and it is assumed that all of the materials are authentic and credible.
- Most research of the elderly that is utilized in this study focus on western countries, particularly the United States, and it is assumed that these findings can also be applied in other cultures.

## **1.6 Scope and Limits**

### **Scope**

- The scope of the elderly in this study refers to the population age 65 and above.
- There are various challenges that the elderly are facing, but this study will mainly focus on solving problems existing in daily activities in the bathroom.
- This study will mainly discuss how to design smart devices.

### **Limits**

- Though the purpose of this study is assisting the elderly using smart home products, there may exist some situations in which smart devices are not the best solution.
- Smart devices in this study will be designed based on technology existing and probable within the next 5 years.
- According to different bathroom conditions and sizes, the effectiveness of this study may be limited in certain situations such as small space.

## **1.7 Procedures and Methods**

### **Procedure 1: Research of the elderly**

Research elderly limitations and supportive statistics. Study elderly acceptance of smart home devices and attitudes towards smart home technology.

### **Procedure 2: Research of elderly bathroom activities**

Analyze and conclude what challenges the elderly are facing when they trying to conduct daily activities in the bathroom. Determine the elderly's pain points and needs, which can also be regarded as corresponding opportunities for design.

### **Procedure 3: Market Research**

Market research consists of two parts. The first part will be bathroom products targeting the senior market. The second part will be the smart home market. Typical products will be selected, and pros and cons will be analyzed.

#### Procedure 4: Research of smart home technology

The definition of “smart” is changing with technology development. This section will study the meaning and advantages of the smart home, as well as the most recent definition and capability of smart devices.

#### Procedure 5: Propose design approach and guidelines

Based on previous study, this thesis will propose an approach and design guidelines for the design of elderly’s smart bathroom during this procedure.

#### Procedure 6: Demonstrations of the application of the design guideline

Representative examples of the application of the proposed guideline will be introduced in this procedure.

### **1.8 Anticipated Outcomes**

The primary outcome of this study is an design approach and design guidelines about how to design a smart bathroom for the elderly. It is anticipated that products designed under this guideline will meet these requirements: (1) User-friendly. The elderly can manipulate or adapt to these products with minimal effort. (2) Smart. Products will be equipped with a certain level of smart technology. (3) Willing to use. The elderly will be willing to use these products. (4) Solve users’ pain points. Existing problems will be analyzed and listed. Products designed under this guideline will be capable of solving those problems.

Generally, it is anticipated that the elderly's living environment will be improved, their independence will be strengthened, and they will be capable of living in their homes longer.



## Chapter 2

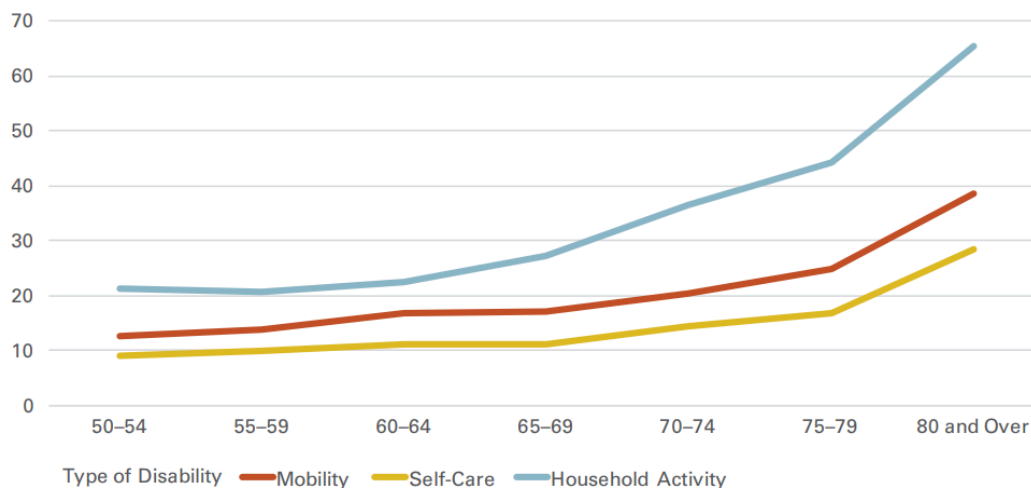
### Literature Review

#### 2.1 Characteristics of Elderly People

##### 2.1.1 Background of the Elderly Population

Population aging is occurring throughout the world. In some regions, such as North America and Europe, the population aged 60 or over has already exceeded 20%. Further, the population aged 60 or over is growing faster than all younger age groups. In the near future, by 2050, all regions of the world except Africa will have nearly a quarter or more of their population at ages 60 and above. Also, globally, life expectancy at birth is projected to rise steadily to 77 years in 2045-2050 (United Nations, 2017). Obviously, with the increase of senior population and life expectancy, the elderly's living condition and life quality become even more important.

At the same time, according to a survey of more than 4,500 people age 50 and above, 87% of people age 65+ and 71% of people age 50-64 prefer to stay in their current home and community as they age, which is known as "Aging in Place" (AARP, 2014).



**Fig. 1. Share of Population with Disabilities by Age Group (Percent)** (Joint Center for Housing Studies, 2016, p.38)

Disability related to:	Difficulty with
Mobility	<ul style="list-style-type: none"> <li>• Walking</li> <li>• Transferring in and out of Bed</li> <li>• Climbing Stairs</li> </ul>
Self-care	<ul style="list-style-type: none"> <li>• Eating</li> <li>• Dressing</li> <li>• Toileting</li> <li>• Bathing</li> </ul>
Household activity	<ul style="list-style-type: none"> <li>• Meal Preparation</li> <li>• Food Shopping</li> <li>• Using Telephone</li> <li>• Taking Medication</li> <li>• Money Management</li> <li>• Housework</li> <li>• Driving</li> </ul>

**Fig. 2. Chart of Disability and Related Difficulties** (Joint Center for Housing Studies, 2016, p.37)

However, with age, for people aging in place, declines in physical, sensory and cognitive functioning lead to greater incidence of disabilities related to mobility, self-care, and household activities (Joint Center for Housing Studies, 2016, p.8) (Fig. 1&2). The elderly are no longer capable of manipulating devices or furniture with which they used to be familiar. A house that is inadequate for the needs of the people living in it, never becomes a home (Demirbilek & Demirkan, 2004). In order to compensate these limitations and help the elderly aging in place, new forms of products need to be developed.

### 2.1.2 Physical Limitations of the Elderly

From a physiological perspective, both the elderly’s height and strength are likely to decrease with aging. Men’s height may decrease 5% and women’s height may decrease 6% due to the shrinkage of cartilage in spine. Different levels of strength loss occur in different body parts. For example, one’s hand strength may decline 16-40% while arm and leg strength may decline

50%, and most elderly people barely exercise to keep muscles toned (Nussbaumer, 2014, p. 232). Typically, in comparison to upper limbs, lower limbs show greater level of muscle-strength loss (Milanović et al., 2013). Also, the elderly may even be affected by arthritis, which will lead to the loss of dexterity (Nussbaumer, 2014, p. 232). The primary problem caused by physical ability degradation is immobility. For examples, in some home settings, the elderly cannot climb stairs and have difficulties passing thresholds between rooms (Iwarsson, Isacson, & Lanke, 1998, p. 173).

Consumers, families and healthcare professionals commonly agree that physical settings are critical factors in allowing frail individuals to live more independently. Physical conditions of the elderly and the environment need to be fully considered to maintain the elderly's level of activity (Iwarsson et al., 1998, pp. 173-174).

It is also worth noting that in order to obtain greater stability when standing or walking in their own, large numbers of the elderly use assistive tools such as canes, walkers, wheelchairs and wheelchair scooters (Nussbaumer, 2014, p. 232), which will occupy a lot of space and change the person's way of moving. Designers should be aware of the possibility that the elderly may carry an assistive tool when they are designing an elderly living environment.

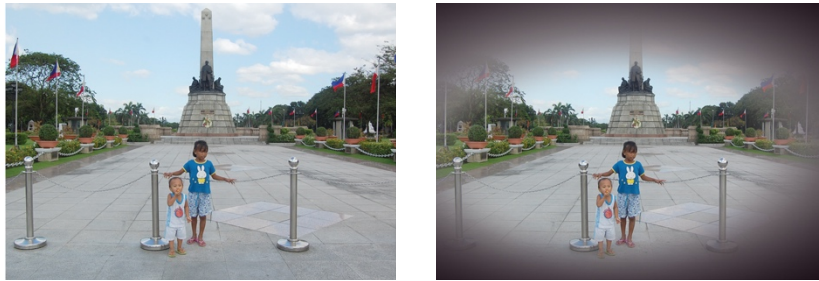
### **2.1.3 Sensory Limitations of the Elderly**

Although each individual experiences are unique, many people in the elderly population suffer from impairments of all five senses: vision, audition, touch, smell and taste.

## Vision Limitations



**Fig. 3. Cataracts (Blurred or Totally Clouded Vision)** ("Vision Conditions: Cataracts," 2010)



**Fig. 4. Glaucoma (Blind Spots in The Field of Vision)** ("Safe And Painless Laser Treatment Now Available To Treat Glaucoma," 2016)



**Fig. 5. AMD (Bad Front Vision and Not Able to See Fine Details)** (Duong, 2018)

The degradation of vision can be categorized into several aspects: Firstly, there are several eye diseases related to aging, such as cataracts (Fig. 3) , glaucoma (Fig. 4) and age-related macular degeneration (Fig. 5), which can cause blurred or totally clouded vision, blind spots in the vision field, and incapability of seeing fine details respectively; secondly, the elderly are susceptible to light changes, and often have to make an effort to adjust themselves to different environment. This

change can also make it difficult for the elderly to recognize information presented on shiny surfaces; thirdly, the elderly may also experience limitation in depth perception (Nussbaumer, 2014, p. 162); fourthly, for the elderly, color contrast between background and objects can become more ambiguous. Compared with young people, the perception of blue color is almost lost, being regarded as achromatic color (Tanaka et al., 2011, pp. 91-94). Some senior people will wear glasses to compensate vision impairments. In some extreme conditions, such as showering, people may take off glasses and lose vision entirely, which also needs to be considered.

### **Hearing Limitations**

The prevalence of a hearing impairment also increases with age. Between 25% and 40% of the population aged 65 years or older is hearing impaired. This prevalence rises with age, ranging from 40% to 66% in patients older than 75 years, and more than 80% in patients older than 85 years (Yueh, Shapiro, MacLean, & Shekelle, 2003). Main symptoms of hearing impairments are reduced sensitivity to pure tones, signal distortion, difficulty in localization and in understanding speech in noisy situations (López-Torres Hidalgo et al., 2009).

### **Touch Limitations**

The decline in touch perception is considered as a signal of the reduction of both central and peripheral nervous systems. In other words, the elderly are not as sensitive to touch, vibration, spatial acuity pain and temperature changes as the young are (Wickremaratchi & Llewelyn, 2006). Also, their skin is not hydrated as it used to be, which can limit their performance on touch screens.

### **Taste and Smell Limitations**

Most individuals begin to suffer taste and smell loss by the age of 60 and more significant losses when over the age of 70 (Schiffman, 1993). It should be noted that both taste and smell are

important warning systems for danger (e.g., smoke, spoiled food, gas leaks) (Nussbaumer, 2014, p. 166).

Generally, the elderly are less sensitive to information surrounding them, and are more likely to miss some sensory information in the environment, which, to some extent, causes the difficulties of living and finishing ADLs and IADLs independently. This limited amount of information may even cause negative feelings such as confusion and uncertainty. Further, if someone is unable to receive one input of information, the risk of missing other forms of information increases as well. The lack of information can make it more difficult to make certain decisions and increases the possibility of making errors. In addition, a sensory impairment is likely to affect a person's feelings (Schifferstein & Desmet, 2007, pp. 6-7).

#### **2.1.4 Cognitive Limitations of the Elderly**

It has been estimated that perhaps as many as 20% of people aged 65 and over are experiencing mild cognitive impairment (MCI), which is defined as cognitive impairment in at least one aspect of cognitive functioning, with no sign of dementia and no significant decline in functional activities of daily life (Sixsmith, 2013). People with MCI are more likely to develop dementia and other cognitive diseases ("Mild Cognitive Impairment (MCI),").

Memory loss is one of the typical symptoms of cognitive impairment which can influence the elderly's daily activity negatively. Memory is divided into 4 categories: Working memory (the short time allowed for pondering about newly acquired information such as remembering telephone number); Prospective memory (remembering to do something in the future); Semantic memory (general knowledge about language and the world at large); Procedural memory (the knowledge how tasks have to be performed). Among the four types of information, aging will

affect working and prospective memory most. Working memory degradation can cause the elderly's incapability to deal with large amount of information during a given time. Prospective memory deterioration can cause loss of remembrance of event-based tasks (turn off the oven when buzzer sounds) and even greater loss of remembrance of time-based tasks (take pills at 4pm). Semantic memory shows no deficits with age. Though the elderly may require more time to obtain new skills, procedural memory remains largely intact with age (Farage, Miller, Ajayi, & Hutchins, 2012; Riemersma, 2000).

For communication, the slower processing speed of the working memory presents a functional limitation for listening and comprehension. To make matters worse, the ability to discriminate between "signal" and "noise" diminishes with age (Riemersma, 2000).

Also, it takes longer for the elderly to orient attention from one thing to another. They are less able to inhibit irrelevant information. Speed and multi-tasking (e.g. looking for street signs while driving) can also become a challenge (Farage et al., 2012).

Cognitive impairment is associated with decline in performance of instrumental activities of daily living (IADL) (Rebok et al., 2014), which includes independent living abilities such as shopping, cooking and managing medications. Through careful design of the interaction between the elderly and information, existing cognitive impairments can be compensated for, and the elderly will recover their capability to cope with IADLs.

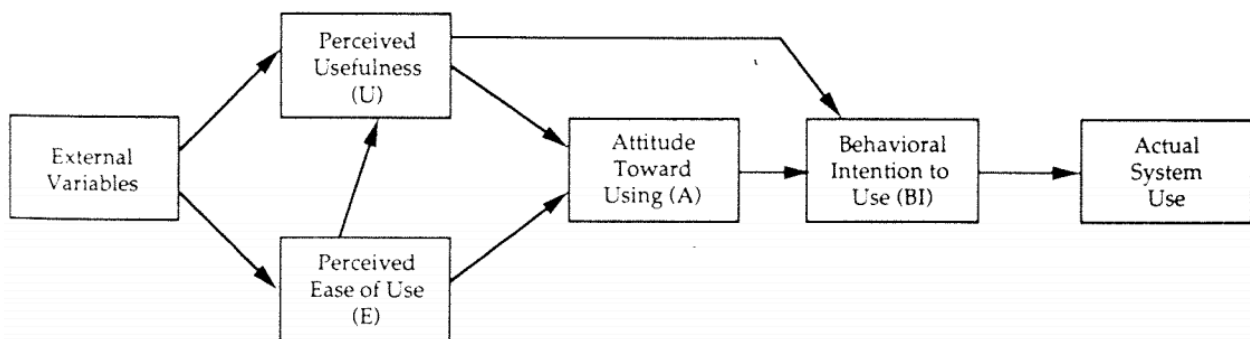
### **2.1.5 Attitude Towards and Acceptance of Smart Home Technology of the Elderly**

As aging continues, the elderly's mobility, self-care and household abilities inevitably decline. However, because of various reasons such as high cost, dignity and their dislike of new environments, many elderly persons refuse to be accommodated in nursing homes. In

consideration of their desire to age in place and their physiological changes, it is necessary to provide them with a new form of assistance so that they can be empowered to maintain autonomy, take care of themselves while safety is ensured, and live a satisfactory life. Home-based assistive technology has great potential to play a role in this challenge, which can potentially compensate for the elderly's function impairments and assist the elderly to finish ADLs and IADLs.

However, there are some indications that the elderly may not be willing to use products which are designed especially for the senior population. For example, the Jitterbug cell phone, equipped with giant buttons, was designed to be easy to use for the elderly. Though Jitterbug is a success from the usability perspective, it makes users feel “being old” when using it (Fallon, 2012). Elderly attitudes and perceptions of technological products should be carefully studied to assure the effectiveness of this study. So, rather than impose technology on the elderly, designers should fully consider factors that might hinder the acceptance of the elderly of new technologies, as well as factors that will help the elderly perceive the advantages of technology.

### 2.1.5.1 Technology Acceptance Model (TAM)



**Fig. 6. Technology Acceptance Model (TAM)** (Davis, Bagozzi, & Warshaw, 1989)

Several models have been proposed to study user acceptance behavior and factors of introduced technology, one of the most well-known models is Davis's TAM (Technology



Acceptance Model) model (Davis, 1989; Steele et al., 2009) (Fig. 6). According to TAM, two factors determine whether users will reject or accept technology: perceived usefulness (PU) and perceived ease of use (PEOU). To be precise, users will be more likely to adopt a new technological product when they believe it will help them perform their job better and the performance benefits are outweighed by the effort of learning the product.

TAM model is applicable to customers from all generations. However, considering the differences between the senior population and other generations, this study will not apply TAM model directly. Instead, factors that will influence elderly acceptance of using technology at home will be listed through comprehensive study of related literature. Six factors are discovered from literature and will be introduced next. Among them, two fundamental factors, usability and evaluation of functions and features, are similar to PEOU and PU from the TAM model.

### **2.1.5.2 Factors That Influence Elderly Acceptance of Smart Home Technology**

#### **Evaluation of Functions and Features**

The most basic factor that can influence the decision of an elderly person using smart technology at home is the capability of functions, and how those products will influence and improve their life (Coughlin, Ambrosio, Reimer, & Pratt, 2007). It is vital that technology solve practical problems in daily life, which requires comprehensive research of pain points of the elderly. Once someone has perceived the usefulness of technology, they will be more likely to move forward and begin to study, purchase or use technology. This factor is similar to PU in the TAM model.

Also, since the advantages of reactive functions (detecting emergencies) are easier to be perceived by the elderly than proactive functions (monitor conditions and predict trends) (Demiris,

Hensel, Skubic, & Rantz, 2008), they prefer reactive functions. However, in some cases, proactive functions are equally as important as reactive functions, and it is necessary to raise awareness of that.

### **Usability**

If the elderly have difficulty interpreting new products when they are learning or trying to use them, they will consider the purchase as risky, and will prefer to function without the product (Jia, Lu, & Wajda, 2015). Actually, a large portion of elderly people have expressed fear and anxiety towards new technology. These negative feelings come from various reasons. The majority of them indicate that some products are hard to understand. Also, some of them are afraid of misusing the products, which may cause malfunction. For these considerations, it is suggested to limit functions that need to be operated or controlled by the elderly. In some cases, elderly people said the interaction with new products can be “an automated thing” or “as simple as push the button”. In other words, no matter whether physical products or interfaces, it is important to keep them as simple as possible to allow users to understand how to interact with products quickly and effortlessly (Steele et al., 2009). This factor is relevant to PEOU in the TAM model. Good usability can increase the possibility of the elderly’s adoption of new technology.

### **Autonomy Level**

Assistive technology is widely regarded as an approach to promote independence and autonomy of the elderly. However, on the contrary, much research has expressed worries that new technology may actually diminish an elderly person’s autonomy.

Firstly, the elderly do not want to be restricted by limited choices provided by new technology. Instead, they wish to be allowed to take risks in trying new choices. For example, they do not want to be reported automatically every time when they fall, because they want to try to

stand up by themselves, and they prefer to report falls manually when they cannot cope with it (Zwijssen, Niemeijer, & Hertogh, 2011). To some extent, this point contradicts previous studies that the elderly prefer simple and effortless products, which means designers have to reach a balance between flexibility and automation.

Secondly, elderly person are often afraid of being over reliant on technology and losing their ability to live independently. For example, the elderly may only remember to turn off the stove when they are informed to (Zwijssen et al., 2011). Also, when they are accustomed to assistive products, their activity level may be reduced, losing autonomy eventually.

### **Privacy**

Privacy is an important concern for all human beings, and also for the elderly. They often reject being monitored constantly by cameras (Steele et al., 2009). Moreover, they are worried about information abuse. Some prefer to preview their information before sending it out, and recipients of their information also need to be fully evaluated (Demiris et al., 2008). However, it is worth noting that, when the perceived advantages of sharing private information outweighed potential risks, the elderly often would give up their privacy. In other words, they place their preference on ensuring that help is readily available over privacy or the confidentiality of their health information (Steele et al., 2009).

### **Social Contact**

While assisting the elderly with their daily activities and helping them age in place, new technology can also isolate them. Technology makes long-distance care possible, which has replaced human contact and human care. However, many elderly people and professionals believe that good care cannot exist without social interaction. Further, some people look forward to caregivers' visits, which is an opportunity for them to communicate with the outside world

(Zwijssen et al., 2011). Actually, new products can increase communication through wireless technology. Helping the elderly maintain or improve communication with others through new technology can be beneficial to increase their acceptance of new technology.

### **Cost**

Cost is one of the main determinants in evaluating elderly acceptance of technology. Even though the elderly are willing to embrace new technology, they may not utilize it if its cost is substantial (Steele et al., 2009). Also, the cost of maintenance and repairs should also be considered to lower potential expenditures.

## **2.2 Bathroom in an Elderly Person's Home**

Historically, compared with other rooms at home, the bathroom has not seen much evolution. For example, household bathtubs and showers, first invented in 1700 BC, have remain virtually unchanged, and their forms are almost identical to the bathtub forms that were used 400 hundred years ago (Mullick, 1993). Does it mean our bathrooms are so perfect that they do not require improvements anymore?

The design of bathroom does not reflect a lifespan perspective. Children begin to use the bathroom on their own at 6-7 years of age, and they continue to do so until they are about 50-60 years old. Beyond this age, people begin to lose their ability of performing daily activities independently, and they start to utilize external assistance to finish activities such as bathing, toileting and grooming. There are numerous assistive bathroom products targeting the elderly in the market, such as grab bars which make up for the inadequate support of mobility and stability, floormats that overcome the danger of slippery bathroom floor surfaces, and bath seats as a

reminder of the elderly's inability to stand while bathing (Mullick, 1993). All of these products send the message that a better bathroom needs to be developed, especially for the elderly.

Although the elderly can have great difficulties coping with activities in the bathroom and are facing potential risks to perform independently, they often prefer to obtain assistance from products and technology rather than from a real person (Giuliani, Scopelliti, & Fornara, 2005). Thus, it is necessary to develop an assistive bathroom solution that can respond to the needs of the elderly population.

This section will present the findings of an interview with staff from Alacare, a local in-home health provider. Then, it will describe two typical activities in the bathroom: bathing/showering and toileting, which can also be the most troublesome tasks for the elderly. Detailed difficulties will be illustrated to demonstrate the activity level of the elderly. After that, a card sorting method will be used to categorize and label existing pain points of the elderly, which will be the checklist for future design of the elderly's bathroom.

### **2.2.1 Living Conditions of Elderly People- Interview with Alacare**

Alacare is a regional in-home health provider chain. They mainly provide home health services and hospice services. In order to investigate the level of ADL and IADL of the elderly living at home, I interviewed two expert staff members (a physical therapist and a nurse) working at Alacare. Both of them have worked with dozens of elderly customers, and their observations of the elderly can be considered to be broad based. The questions of the interview can be found in Appendix 1. During the research, questions were subject to change on the basis of the conversation, and were used to verify Literature Review information.

According to the staff members' observation, the elderly often encounter challenges in housekeeping (laundry, throw trash, clean), self-care (toileting, bathing, cooking), mobility and isolation. Many problems are exacerbated by cognitive problems, poor financial situation and inadequate design of their homes (narrow doors, high counters).

When asked what is the most difficult task for the elderly to finish independently, both staff members stated that bathing and toileting are the most problematic activities. Also, they mentioned that in their experience bathroom should be the first room to be remodeled to fit the elderly's decreasing mobility. According to their experience helping the elderly with their ADLs, an ideal bathroom should be small but have sufficient space, and it should be efficient; only necessary fixtures should be installed in the bathroom.

These findings are in accord with literature, which indicates that, at home, the bathroom poses the most threats to safety (Mullick, 1993). Although there exist numerous aspects that design can help the elderly with, considering their urgent needs of an effective bathroom, this study will focus on improving the design of the bathrooms.

## **2.2.2 Description of Typical Bathroom Activities of Elderly People**

### **2.2.2.1 Bathing**

Bathing cleans skin and removes accumulated foreign from the body. Bathing does not only serve a functional purpose, but also is a way to revive and refresh through the washing process, and a means of enabling social interactions (Ahluwalia, Gill, Baker, & Fried, 2010; Mullick, 1993). With a better and cleaner appearance, people are more confident to step out of their homes and get involved in social activities. Bathing difficulties exist in various aspects.

Firstly, there are often difficulties in dressing and taking off clothes (Naik, Concato, & Gill, 2004; Parker & Thorslund, 1991). For homes that are not equipped with heating systems, the elderly may be exposed to cold temperature before, during and after bathing. Due to physical degradations, they may be more susceptible to thermal conditions, which is one of the reasons why many deaths of the elderly are reported in winter (Kanda, Tsuchiya, Seto, Ohnaka, & Tochiara, 1995; Mullick, 1993).

Opening faucets and adjusting water temperature can also be troublesome for many elderly people. It is hard for the elderly to bend and reach controls from outside of the tub. Sometimes, they may risk their safety and over-exert themselves in order to reach the water controls outside of the tub (Mullick, 1993). A large population of the elderly suffer from arthritis, which increases the difficulties of operating and fine-tuning the water control. Moreover, water controls can be difficult to use due to the problem of understanding the color-coded signage regarding temperature, and the complex operation may demand push and turn at the same time (Naik et al., 2004). People who lack touch sensation misadjust water temperature frequently, which causes scalding as well (Mullick, 1993).

The most common problems for the elderly are mobility and stability. Maintaining balance while getting in and out of the tub can be especially difficult for them. Often, they may utilize nearby objects such as the rim of the tub to keep stable, which can be quite dangerous. Those unable to make safe transfers sometimes abandon tub-oriented bathing. When bathing, due to the loss of dexterity and arthritis, the elderly can have difficulty bending over and kneeling down so that they are unable to reach “high” and “low” and need help with haircare and footcare. They may attempt to challenge themselves, which increases the possibility of injuries and falls. Technical tools such as grab bars, bathtub chairs and benches are also widely used to compensate for poor

balance. However, entering and exiting the bathtub are still the activities most likely to lead to slippage and falls (Mullick, 1993; Naik et al., 2004; Parker & Thorslund, 1991). Limited reach, poor grasp strength, low levels of light in the tub area, and unorganized and inadequate storage around the tub make it difficult to reach and utilize nearby fixtures and objects during bathing, and can cause dangers (Mullick, 1993).

A fall is the most unwanted accident in the bathroom. Falls happen typically after bathing due to the slippery floor and limited stability. Smooth floors and rugs can also escalate the possibility of falling (“Aging in Place Bathrooms,” n.d.).

A great number of elderly and their relatives have noticed these potential troubles during bathing, and many efforts have been made to address them. Bathroom adaptations are common and involve the installation of showers and one-hand-controls. Walking aids are also widely adopted. Even some people who are able to walk without a support have an aid, because they are afraid of falling. However, because of the raised thresholds and narrow space in the bathroom, many elderly people leave their aid by the door and support themselves by holding on to nearby objects such as the door frame, the sink and the edge of the bathtub (Parker & Thorslund, 1991).

Some have forced themselves to change their usual mode by restricting their method or frequency of bathing (Ahluwalia et al., 2010). A sponge bath on a chair in the kitchen is a choice, and in some cases, showers have been installed in place of the bathtubs (Parker & Thorslund, 1991). However, accessible showers are not free of problems, since the elderly still have difficulties reaching and using bathing accessories while sitting on built-in seats (Mullick, 1993).

Although most express the desire to stay independent in bathing, the rest wish to bath securely and are willing to receive help from another person (Ahluwalia et al., 2010). However, the narrow space near the bathtub and awkward layout of the bathroom often make it difficult for



caregivers to move freely. Transferring people in and out of the tub is claimed to be the most problematic part of caregivers' jobs (Mullick, 1993).

#### **2.2.2.2 Toileting**

In the general population of adults age 65 years and older who are living at home, the prevalence of toileting disability is 6% (Dudgeon et al., 2008; Talley et al., 2014). Toileting troubles for the elderly are made of various aspects.

First of all, elderly people with poor eyesight and limited depth perception often cannot distinguish the white toilet accurately from the white bathroom background, and the wall from the floor. Storage space for walking aids such as wheel chairs and canes is also vital for the elderly with limited physical ability (Dekker, Buzink, Molenbroek, & Bruin, 2011; Parker & Thorslund, 1991).

Similar to bathing, mobility and stability are the most common problems during toileting. Diminished physical ability can cause difficulties when the elderly are trying to undress, turn around, sit down, stand up and dress. Regular toilet seats are unsafe for the elderly, particularly people with obesity. They often cannot fit small toilet seats, and improper positioning is uncomfortable and unsafe (Dekker et al., 2011; Parker & Thorslund, 1991). The most common technical aid to deal with sitting down and standing up is raised toilets. However, raised toilets may lead to other problems such as prolonged sitting on the toilet due to an unfavorable posture. Due to the loss of balance and diminished muscle flexibility, cleaning intimate body parts is also a problem for the elderly (Dekker, Buzink, Molenbroek, & Bruin, 2007).

### **2.2.3 Challenges in Bathroom for The Elderly**

There are various challenges that the elderly may encounter in their bathroom. In order to propose a checklist of pain points for future design, the behavior in the bathroom need to be fully evaluated. Using the card sorting method, 14 articles (Appendix 2) are selected from multiple databases discussing elderly limitations in the bathroom, from which key words of problems were extracted point by point and categorized into multiple topics. Below are the topics which represent the challenges of the elderly in their bathrooms.

It should be noted that the intention of this study is regaining independence in the bathroom. So, this section will mainly discuss challenges that the elderly are facing when they are in the bathroom alone.

#### **Mobility**

Mobility is one of the most fundamental problems hindering one's activities in bathrooms. Due to physical limitations, the elderly often cannot make movements freely, so they can encounter problems when they are trying to transfer from a to b (getting in/out of bathtub/shower) and change movements (sit down/get up from toilet seat, turn around, dress/undress). With sufficient support, they can not only move independently but also maintain safety.

#### **Stability**

Stability is another prevalent problem. Due to degraded balance and endurance, the elderly are not able to maintain the same posture (standing while bathing/showering) for a long time. In this condition, the elderly will need objects they can grasp to maintain stability. Also, they are more likely to become fatigued and weak during bathing or showering, which affects their stability.

## **Dexterity**

During aging, the elderly can lose both upper and lower limb strength gradually, and a great portion suffer from arthritis. Because of that, they may have problems in the following two aspects.

Firstly, some of the elderly have reaching and bending problems. With limited reach, they may struggle to obtain objects placed too high, low or far, such as objects on high counter tops. Reaching is much more problematic for wheelchair users. Also, because of loss of dexterity, the elderly may not be capable of washing or drying their whole body. Dressing and undressing are also problems for them. Some parts of their body, such as feet, hair and back are particularly difficult to reach.

Secondly, the elderly may have limited hand strength. Grasping and utilizing objects can be difficult or even painful for them.

## **Assistive tools**

Assistive devices for walking are common among the senior population. Sufficient space for moving and storage should be provided for assistive tools users.

## **Sensory impairments**

Among the five senses, visual and touch impairments cause the most significant difficulties in the bathroom. With visual defects and the low level of illumination in some bathrooms, the elderly cannot see nearby objects such as the faucet. Distinguishing edges of surfaces and objects from the environment background can also be troublesome for people with poor depth perception. Touch impairment mainly leads to misjudgment of temperature.

### **Bathroom environment**

There are several considerations of the bathroom environment. Firstly, bathroom layout can cause problems such as obstacles and inaccessible areas for wheelchair users. Also, good organization is essential for storing everything in place. Secondly, inadequate bathroom space can result in inconvenience for both the elderly and caregivers. Thirdly, the environmental quality such as proper temperature and low level of noises can diminish discomfort of the elderly.

### **The elderly's understanding of products**

Some seniors have difficulty utilizing products, such as misunderstanding of color-coded temperatures and complex operation of faucets. The usage of products should be as simple as possible. More importantly, it should accord with users' experience so that they can understand them with minimal effort.

### **Encouragement**

Some seniors find maintaining personal hygiene, such as mouth care troublesome so that they just give up. In this case, encouragement should be provided for motivation.

### **Emergency**

Terrible accidents can happen in the bathroom. Falling is the most common reason of injuries in the bathroom. Slippery floors, sharp edges and rugs on the floor should be avoided to ensure safety. Solutions such as emergency contacts should be accessible for the elderly when they are in danger, even in the bathroom.

### **Flexible needs**

Another consideration is that others living on the property need to use the bathroom as well. Further, the elderly's needs are changing as they are getting older. This means, to some degree, the bathroom should be flexible or adjustable to meet multiple users' changing needs.

## 2.3 Smart Home

In many cases, the elderly may suffer from long-term disabilities, which do not require critical support from hospitals or nursing homes. It can be inefficient and costly for the elderly to stay in hospitals and nursing homes for an uncertain period of time (Alam et al., 2012), and it is often against the elderly's desire to stay at home. What they need is a safe and supportive environment for living, and smart homes have enormous potential in supporting the elderly in this field (Robles & Kim, 2010).

Smart home technology is developing rapidly. In order to clarify the definition and potential of it, in this section, the history and recent development of smart home technology will be discussed, as well as key enabling technologies.

In order to ensure the accuracy and timeliness of the information in this section, most of the references cited in this section are published after 2010. References cited before 2010 will be noted.

### 2.3.1 Development and Definition of Smart Home Technology



**Fig. 7. The 1957 Frigidaire “Dream Kitchen of Tomorrow” (Eveleth, 2015)**

The introduction of electricity fueled the emergence of a range of appliances designed for the home, leading to the futuristic demonstration of “homes of tomorrow” in the 1950s and 1960s, which are the earlier concepts of smart home (Fig. 7). The second stage of smart home evolution involved the growth in information technology in the 1980s and 1990s. The wide acceptance of using computers have made homes a part of information networks and systems, which extended their meaning from a place of leisure to a technologically efficient place. The third stage of smart home evaluation involved the arrival of digital interactive technologies in the early twenty-first century, leading to home automation systems and to the development of the Internet of Things (IoT) (Chambers, 2016, p. 152) .

From the history of smart homes, it can be concluded that the advancements in the field of smart homes are not an isolated case. The development of smart homes takes place within the society and is influenced by trends within that society (Robles & Kim, 2010). Considering current trends in the field, an unformal definition of smart home is proposed:

Smart home is an application of ubiquitous computing that is able to provide user context-aware automated or assistive services in the form of ambient intelligence, remote home control or home automation (Alam et al., 2012).

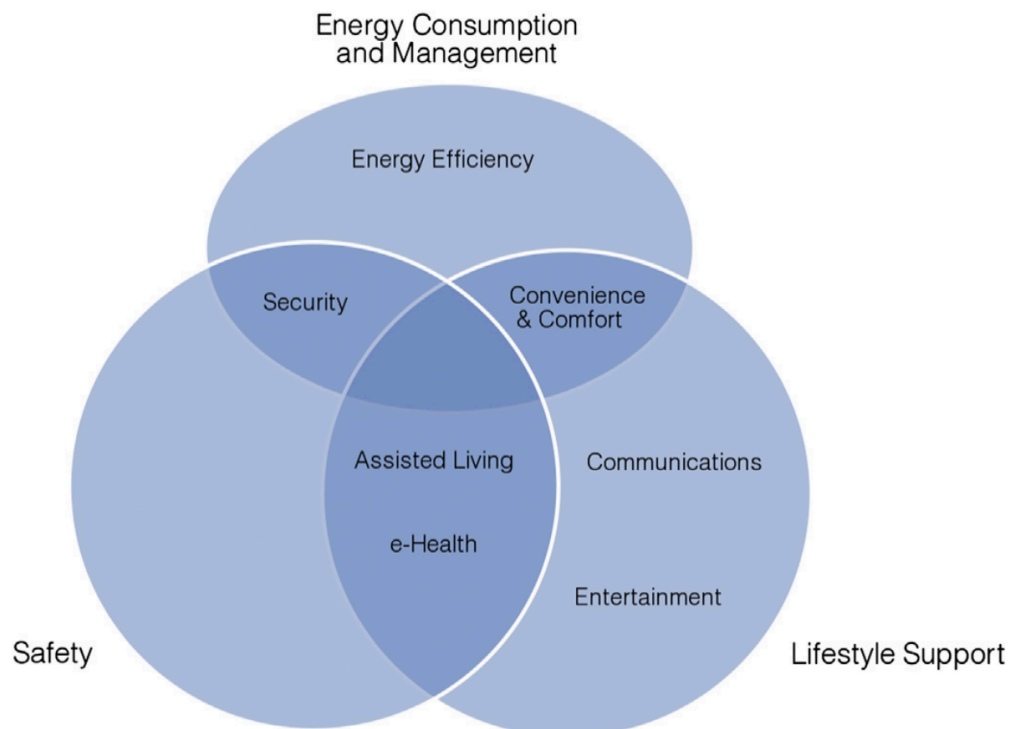
Four elements are needed to set up a smart home system (Alam et al., 2012; Balta-Ozkan, Davidson, Bicket, & Whitmarsh, 2013; Sripan, Lin, Petchlorlean, & Ketcham, 2012):

1. A communications network (Smart home equipment is connected through a communication network to share and exchange information. It can be either wired or wireless.)

2. Intelligent controllers (The gateway to manage the smart home system by sending data or signals. Controllers can be remote control, or built in existing products such as smartphones, tablets and computers.)
3. Data acquisition equipment and devices (Assesses the status of residents and their environments. These monitoring devices can be classified into three categories: sensors, physiological devices, and multimedia devices.)
4. Smart features (Products that respond to information from sensors or user instructions as well as the system provider.)

### 2.3.2 Smart Home Market

The global home automation market in 2014 was valued at around US\$ 5 billion, and is estimated to reach US\$ 21 billion by 2020 (Parag & Sovacool, 2016).

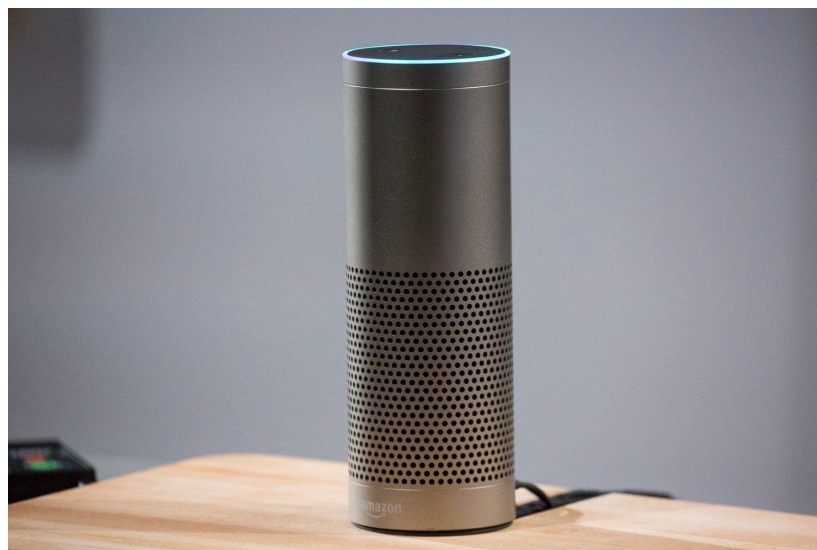


**Fig. 8. Types of Smart Home Products and Services** (Balta-Ozkan et al., 2013)

Basing on people's needs, types of products and services smart home can be categorized into three overarching and interconnected categories: energy consumption and management, safety, and lifestyle support (Fig. 8). Under these three categories, there are several smaller and more specific categories: energy efficiency, security, assisted living, e-health, convenient and comfort, communication and entertainment (Balta-Ozkan et al., 2013).



**Fig. 9. Ring Video Doorbell ("RING Doorbells,")**



**Fig. 10. Amazon Echo (Shaban, 2018)**



All smart home products in the market belong to one or several categories mentioned above. For example, the video doorbell called Ring (Fig. 9) allows users to see who is at the front door via their mobile phone and communicate with visitors, which mainly satisfies the security need of users. Another example, the smart speaker Echo (Fig. 10), has lot more functions. Users can communicate with the voice assistant Alexa built in it. With simple commands, Alexa can help users to look up information such as weather and time. Alexa can also amuse users, tell jokes or play music. Moreover, if Echo is connected with other products such as TV or the Ring which we just mentioned, it can work as a controller of other devices, which is the concept of IoT.

### **2.3.3 Key Enabling Technologies of Smart Homes**

A smart home is an integration system, which takes advantage of a range of technologies to redefine the ability and role of home appliances and household electrical devices. To be precise, smart home technology enables households to centralize the management and services in a home, providing residents with all-around functions and helping to keep in instant contact with the outside world. Fig. 11 demonstrates different applications for smart home (El-Basioni, El-Kader, & Eissa, 2014, p. 11).

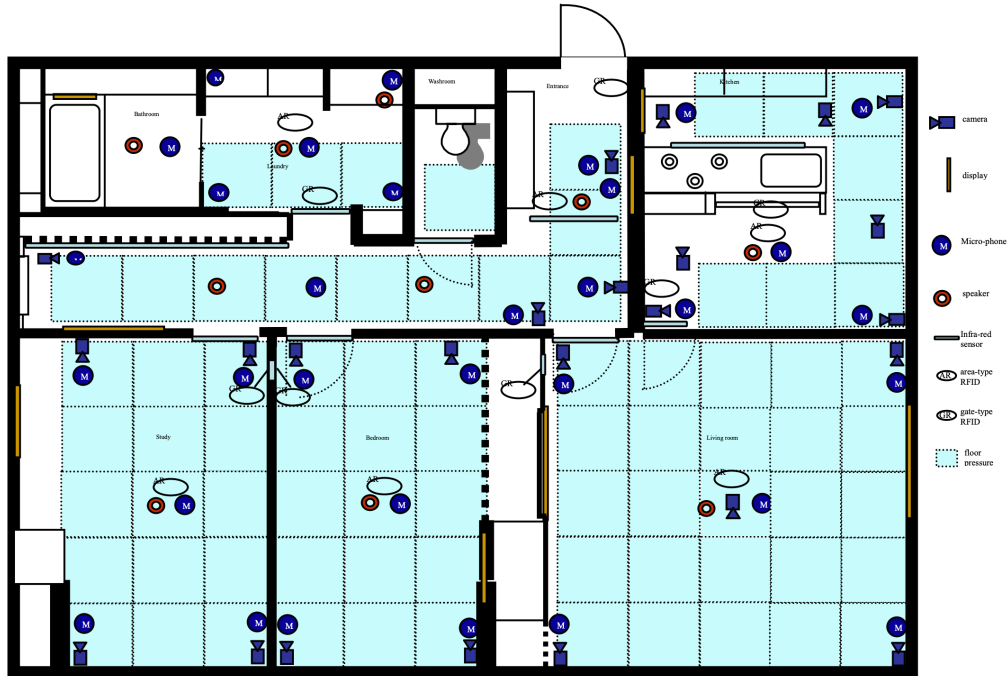


**Figure 11. Smart Home Applications** (El-Basioni et al., 2014)

In this section, in order to figure out how smart home technology works, key enabling technologies of smart homes will be introduced based on current market and recent technology trends.

### **Ubiquitous Home**

The concept of ubiquitous computing is projected to be the next wave in computing, where computer technology is everywhere, combined and inter-connected, but in an unobtrusive way (Solaimani, Bouwman, & Secomandi, 2013). Ubiquitous home emerged from the concept of ubiquitous computing. In a ubiquitous home, the information of residents' activities and environments' condition are collected and utilized without residents being aware of it. Also, ubiquitous home allows residents to control and monitor electronics appliances, such as lights, television, CCTV, door lock, or sensors anywhere and anytime (ubiquity) (Benny, 2016).

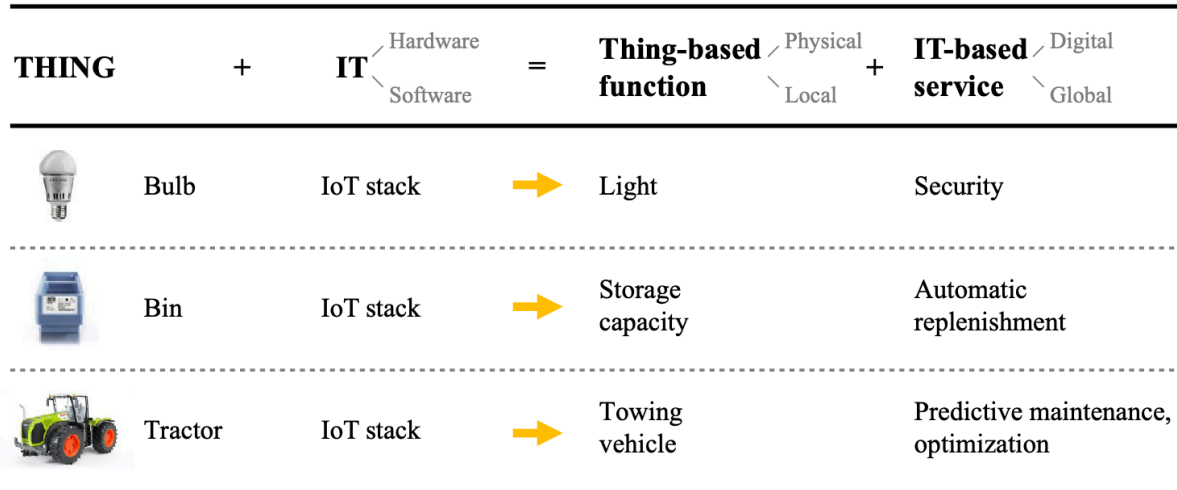


**Fig. 12. Layout of Ubiquitous Home** (Alam et al., 2012)

A typical project in this field is called Ubiquitous Home (Fig. 12), which is a real-life test bed for home context-aware service experiments. The Ubiquitous Home was built in 2004, and experiments were conducted continuously in it in the following years. Cameras, microphones and various sensors are installed in Ubiquitous Home. Experiment's subjects can actually live in Ubiquitous Home as if living in their own house, not in a laboratory (Yamazaki, 2007).

### **Internet of Thing (IoT)**

The Internet of Things (IoT) is a concept that describes how the Internet is being used to link consumer devices and physical assets so that these new endpoints can create and receive a data stream. The IoT has existed for many years. We have already reached the point where the number of things connected to the Internet has surpassed the PCs and mobile devices that connect to the Internet. The number of things that connect to the Internet will continue to increase exponentially (Fenn & LeHong, 2011, p. 23).



**Fig. 13. Logic of Value Creation of IoT Products** (Wortmann & Fluchter, 2015)

Incremental values of everyday products can be generated by IoT. Fig. 13 illustrates the logic of such value creation. It demonstrates that IoT solutions typically combine physical things with IT in the form of hardware and software. As a result, the primary thing-based physical functions of a thing can be enhanced with additional IT-based digital services, which can be accessed not only on a local basis but at a global level (Wortmann & Fluchter, 2015).

IoT can also be applied to create a new concept and wide development space for smart homes to provide intelligence, comfort and to improve the quality of life. Not only devices and appliances can be controlled remotely, but home environments can also be continuously monitored (Piyare, 2013).

### **Assistive Technology (AT)**

In the context of this study, which is to help the elderly prolong or recover their independence in the bathroom, assistive technology is also one of the most important enabling technologies. Assistive technology is an umbrella term. It refers to products, instruments, equipment or technologies specially designed for improving the functioning of a person with disability (Larsson & Östergren, 2011).

AT application is diverse and could be used in several ways. For example, AT can be used for health monitoring, to assist people with dementia in their daily problems, to support social contact or to enhance safety. The possibilities of integrating assistive technologies with an elderly person's own home seem to be endless (Zwijssen et al., 2011).

## **2.4 Conclusion**

In conclusion, the literature review of this study can be divided into three parts: the characteristics of the elderly, elderly difficulties in completing bathroom activities independently and smart home technology and its applications. Firstly, it has illustrated that the elderly are experiencing physical, sensory and cognitive degenerations, which hinder their ability of finishing ADLs and IADLs. Also, designers need to fully respect the elderly's behavior and thinking habits to increase the possibility of acceptance and adoption of new technologies and products. In the next section, it was proposed that finishing bathroom activities such as bathing and toileting is the most troublesome task for the elderly, and their challenges are listed and explained comprehensively. In the last section, the literature review goes through the history and recent development of smart home technologies, which is regarded as having enormous potential in assisting living. Key features and enabling technologies are also clarified to ensure the operability of this study.

In the next chapter, in order to assist designers to design a bathroom that is able to help the elderly finish bathroom activities smartly, a design guideline will be proposed. According to the design guideline, the scope of application will be clarified, a checklist of common problems existing in bathroom environments will be provided, several principles regarding smart bathroom design will be introduced, and the whole process of design will be planned to ensure a systematic

result. It is anticipated product designers, interior designer and even individual home owners can utilize this guideline to build a smart assistive bathroom for the elderly.

## **Chapter 3**

### **An Approach and Guidelines for the Design of Smart Bathroom Products Considering the Senior Population**

#### **3.1 Overview**

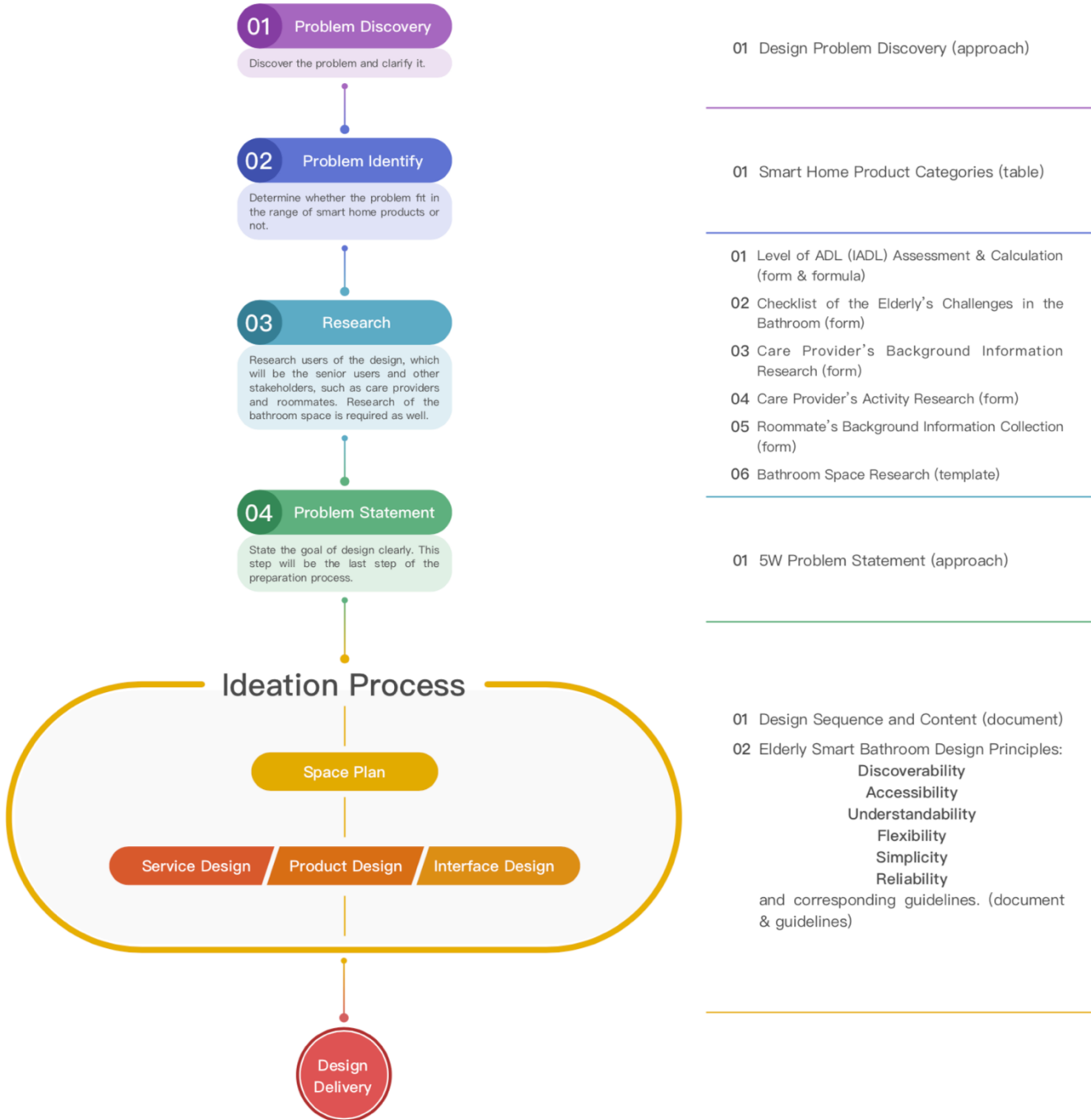
In this chapter, a design guideline will be proposed in order to assist designers who are designing smart assistive bathroom products for the elderly aging in place. The main body of the guideline is seven principles that should be followed during the design process, which include discoverability, accessibility, understandability, flexibility, simplicity and reliability. Guidelines of each principles will also be presented in order to instruct reader how to put the principles into practice. The preparation process of the guideline, which mainly includes problem identification, research and problem statement, will also be introduced to lead the designer to making full use of the design guideline.

This design guideline will not only be beneficial for product designers, but will also assist interior designers and individual home owners to design the bathroom space regardless of new construction or renovation.

### 3.2 Smart Bathroom Design Guideline Considering the Elderly

#### GUIDELINES

#### SUPPORTING MATERIALS



**Fig. 14. Smart Bathroom Design Guideline Considering the Elderly and the List of Supporting Materials**



As shown in Fig.14, the left portion presents the process of following the elderly smart bathroom design approach, which follows three procedures: preparation steps (01-04), ideation process and design delivery. The right portion of Fig.14 introduces supporting materials that designers can choose to utilize, which will help designers obtain better performance when practicing the guideline. A brief explanation of each step will be introduced below:

The preparation procedure begins with problem discovery (01), in which designers will be able to target and clarify problems that they anticipate to solve through the design problem discovery approach. Then, designers need to identify (02) whether the targeted problem fits in the scope of this study or not by comparing the problems with the range of smart home products. After that, designers are required to conduct research (03) of the topic, which is divided into four aspects: research of the elderly aging in place, care providers research, roommates research and bathroom space research. Tools are provided for each aspect of the research, and there is no definite sequence among the four categories. The last step of the preparation process is the problem statement (04), in which designers are suggested to state and describe the problems clearly for the convenience of further design. The 5W problem statement approach is provided to assist designers in this step.

When preparations are completed, designer can start the ideation process, which is the key part of the guideline.

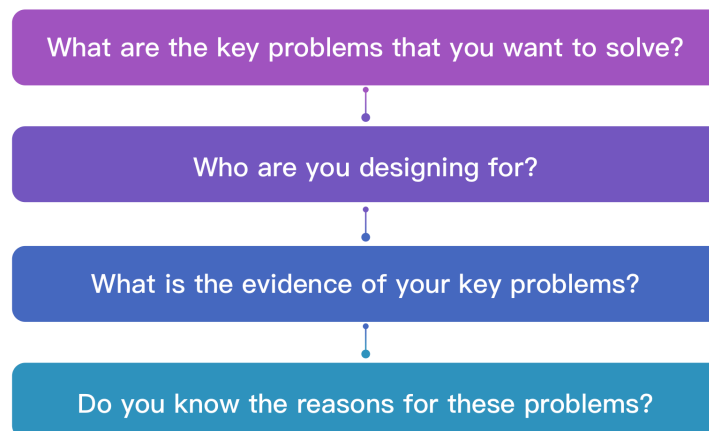
The ideation process starts with the space plan, a prerequisite step, in which designers are required to determine the role of each space partitions and arrange the placement of bathroom. The ideation process also includes service design, product design and interface design, and a strict order does not exist strict order among these three steps. During service design, designers need to consider the services and functions that will be provided by the design. Tangible products, physical and digital interfaces will be designed as well, which are the definition of product design and

interface design respectively. Regardless of the categories, designers always need to follow the six smart bathroom design principles (discoverability, accessibility, understandability, flexibility, simplicity and reliability) so that the elderly and other stakeholders can make full use of the design. Guidelines of each principle are also proposed to ensure the practicability and operability of the principles.

Comprehensive explanation of each procedure will be talked about in the following paragraphs, as well as the method of how to utilize the supporting materials.

### 3.3 Problem Discovery

#### *Design Problem Discovery*



**Fig. 15. Design Problem Discovery Approach**

Discovering design problems is the first step. The purpose of this step is extracting key information of the targeted problem from the designers' ambiguous thinking in the beginning, so that it will be easier for them to determine whether the targeted problems fit in the scope of this study or not and advance through the following process.

A designer can employ the Design Problem Discovery approach (Fig.15) to complete this step. According to the approach, designers need to ask themselves four questions, and each question serves certain goals:

**1. What are the key problems that you want to solve?**

Clarify the ultimate goal of this design.

**2. Who are you designing for?**

Indicate users of this design. Designer should consider both main users and potential stakeholders under this question.

**3. What is the evidence of your key problems?**

Prove the existence of the key problems. Designers need to assure that the proposed problems are not created from imagination or stereotypes.

**4. Do you know the reasons for these problems?**

Explore the essentials of the proposed problems. It will be extremely beneficial for the designer to dig through surface of the issue and search for the real problem to solve.

The form of delivery is not limited. Designers can discuss the questions among the group, or simply write it down on paper.

### 3.4 Problem Identification

Main Category	Sub Category	Description
Automation		The discovered problems will be solved if household appliances can be automated.
Connection	Control	The discovered problems will be solved if users can control home appliances regardless of distance.
	Monitor	The discovered problems will be solved if users can monitor what is happening in and around their homes.
	Communication	The discovered problems will be solved if users can communicate with other stakeholders.

**Tab. 1. Smart Home Product Categories**

In the first chapter, this study has mentioned that not all problems found by the designers can be solved or are proper to be solved by smart home technologies. For example, someone having difficulties distinguishing the white basin from the white bathroom background is one of the challenges we found from the literature review. This problem can be perfectly solved in a “low-tech” way, such as painting the edge of the basin with contrasting colors. Hence, before starting designing smart home products, designers need to decide whether the targeted problems are included in the capability of smart home products or not, which is the purpose of this step: problem identification.

In order to help designers to clarify whether the problems they discovered fit in the scope of this study or not, the table of smart home product categories (Tab.1) is provided.

According to the table, there are two main categories of smart home products, which are automation and connection. Automation means product can function automatically, and

connection means the connection between human and machines and among machines is strengthened. Further, connection can be divided into three sub categories: control, monitor and communication. Control represents that users can control the product freely, without timing or geographic boundaries. Monitor indicates users can monitor what is happening in and around their homes, and communication stands for the convenient communication feature among multiple stake holders and the machines.

After problem discovery, designers can simply check if the content of the problems meets the above categories. If yes, designers can continue to finish the follow-up work, and if no, this guideline may not be applicable to their problems.

### **3.5 Research**

The primary subject of research will be the elderly aging in place, who will be the main users of the design. Needs and conditions of relative stakeholders also required to be considered, which mainly include care providers and roommates. In the end, designers also need to research the overall space of the bathroom, which will help them to obtain a better understanding of the environment. Each category of research and supporting tools will be introduced in the next section.

#### **3.5.1 Research of the Elderly Aging in Place**

##### **3.5.1.1 Assessment of ADL and IADL**

Since the elderly will be the main users of the design, it is vital to research about their basic functioning conditions and challenges they have when they are using the bathroom.

As mentioned in the previous chapter, both ADL (activity of daily living) and IADL (instrumental activity of daily living) are the two important factors representing the functioning

level of the elderly. Below are the tools that can help designers to assess the level of ADL and IADL of the elderly:

### ***Level of ADL Assessment***

<b>ADL Function</b>	<b>Totally Independent</b>	<b>Need Limited Assistance</b>	<b>Need Extensive Assistance</b>	<b>Totally Dependent</b>	<b>Not Applicable</b>	<b>Score</b>
Bathing						
Dressing						
Grooming						
Mouth Care						
Toileting						
Walking						
Climbing Stairs						
Eating						
Average						

***Score:***

Totally Independent = 0      Need Limited Assistance = 1      Need Extensive Assistance = 2

Totally Dependent = 3

***Average:***

$0 \leq n < 1$ : Highly Independent       $1 \leq n < 2$ : Partly Dependent       $2 \leq n \leq 3$ : Highly Dependent

**Tab. 2. Level of ADL Assessment**

### **Level of IADL Assessment**

IADL Function	Totally Independent	Need Limited Assistance	Need Extensive Assistance	Totally Dependent	Not Applicable	Score
Shopping						
Cooking						
Managing Medications						
Using the Phone						
Doing Housework						
Doing Laundry						
Driving or Use Public Transportation						
Managing Finances						
Average						

**Score:**

Totally Independent = 0      Need Limited Assistance = 1      Need Extensive Assistance = 2  
 Totally Dependent = 3

**Average:**

0 ≤ n < 1: Highly Independent      1 ≤ n < 2: Partly Dependent      2 ≤ n ≤ 3: Highly Dependent

**Tab. 3. Level of IADL Assessment**

Assessment of the level of ADL (Tab.2) and IADL (Tab.3) can be accomplished either by stakeholders, such as care providers, or the elderly themselves as a self-assessment tool. It is suggested to put caregivers or other stakeholders in charge of using the tools, particularly when the elderly have cognitive limitation.

The use of these two tools (Tab.2 and Tab.3) are similar. Taking the assessment of the level of ADL (Tab.2) as an example:

1. Firstly, testers need to determine the elderly person’s level of functioning in each ADL functions, and mark in the corresponding blank. There are four degrees of functioning, and the meanings of each degree are listed as below:

Totally independent: The elderly do not need any assistance to finish the activity. They can finish the activity easily.

Need limited assistance: The elderly are able to finish the activity, but they can perform better with assistance.

Need extensive assistance: The elderly are likely to fail if they do not receive any assistance.

Totally dependent: The elderly cannot finish this activity if there is no assistance. They elderly need full assistance with this activity.

Not applicable: The elderly do not do this activity.

2. Secondly, testers need to score each function according to the level of independency:

Totally independent: 0

Need limited assistance: 1

Need extensive assistance: 2

Totally dependent: 3.

Not applicable: Unscored.

3. Thirdly, testers need to calculate the average. Functions that are marked as “not applicable” should not be included in the calculation. The results of calculation are categorized into three meanings:

$0 \leq n < 1$ : Highly independent. The subject is highly independent in the level of ADL functioning.

$1 \leq n < 2$ : Partly dependent. The subject is partly independent in the level of ADL functioning.

$2 \leq n \leq 3$ : Highly dependent. The subject is highly dependent in the level of ADL functioning.



### 3.5.1.2 Checklist of Potential Problems in The Elderly's Bathroom

<b>Checklist of Potential Problems in The Elderly's Bathroom</b>				
<b>(Name of The Activity)</b>				
<b>Category</b>	<b>Problem</b>	<b>Exists</b>	<b>Does Not Exist</b>	<b>Example</b>
Mobility	Transferring from a to b			Getting in/out of bathtub
	Changing movements			Sitting down/Getting up from toilet seat
Stability	Maintaining a same posture			Standing while bathing
Dexterity	Reaching			Dressing/Undressing
	Bending			Footcare
	Using hand strength			Grasping objects such as shampoo bottle
Assistive Tools	Moving assistive tools			Moving with a wheelchair/walker/cane in the bathroom
	Storing assistive tools			Storing the wheelchair/walker/cane in the bathroom
Sensory Impairments	Visual abilities			Distinguish nearby objects without glasses
	Touch abilities			Judging water temperature
Bathroom Environment	Keeping bathroom organized			Finding desired objects such as toothpaste
	Maintaining bathroom environment quality			Temperature and noise level of the bathroom environment
The Elderly's Understanding of Products	Understanding of products			Operating faucets
Encouragement	Finishing all bathroom activities			Brushing teeth every time
Emergency	Avoiding emergencies			Avoiding fallings
	Responding to emergencies			Calling relatives after fallings
Flexible Needs	Fulfilling changing needs of the elderly			Using bathroom after surgery
	Fulfilling needs of other users			Roommates and caregivers can use the bathroom easily

**Tab. 4. Checklist of Potential Problems in the Elderly's Bathroom**

In Chapter Two, ten challenges that the elderly often encounter when they are using the bathroom are concluded and comprehensively explained. During research of the elderly, these ten challenges can be regarded as a checklist (Tab. 4), which will help designers to discover more possible difficulties of the elderly that they may have overlooked, and help designers to explore more potential design opportunities.

As shown in Tab. 4, the first row is the activity that designers are researching. The first left column is the main categories that are found in Chapter Two, and the second left column is the detailed problems that the elderly may have when they are using the bathroom. The right column is typical examples that are provided to interpret the meaning of each problem.

The use of this checklist is straightforward. Firstly, designers should indicate the activity that they are researching, such as bathing, toileting, showering, grooming, dressing and cleaning, and fill the activity into the blank in the first row of the checklist. Secondly, and also lastly, designers can simply check whether they have discovered the problem mentioned in the left two rows or not. If yes, they can mark “exists”, and if no, they should mark “does not exist”.

This checklist will not only help designer clarify the situation, but also assist designers to discover areas that they may have missed during the research.

### **3.5.2 Research of Care Providers**

Care providers are one of the most crucial stakeholders relating to this study. Care providers can be relatives, volunteers or professional caregivers. Their main duty is assisting the elderly to finish daily activities and maintain living quality. Hence, it is very likely that they will appear in the bathroom and help the elderly to accomplish bathroom activities. Although the ultimate purpose of this study is increasing the elderly’s autonomy and letting them age in place

independently as long as possible, the pain points and level of engagement of care providers still need to be considered.

In order to research care providers, two tools are provided, the form for collecting care providers' background information, and the form for investigating care providers' engagement and pain points, which are shown as below:

***Care Provider Background Information Research***

Name		Relationship to the Elderly	
Frequency of Caring the Elderly		Profession	
Organization			
Duty and Responsibility			
Knowledge of the Issue			
Available Resources			
Constraints			

**Tab. 5. Care Provider Background Information Research**

## ***Care Provider Activity Research***

<b>Activity</b>	<b>Participation</b>	<b>Pain Points</b>
Bathing		
Showering		
Toileting		
(un)Dressing		
Grooming		
Maintenance		
Other		

**Tab. 6. Care Provider Activity Research**

In order to fill these two forms (Tab.5 and Tab. 6), designers may need to conduct interviews with care providers or observe the activity of the care providers. It is anticipated that both of these forms can not only be used to investigate personal care givers, but also organizations that are providing services for the elderly.

The form of care providers' background information research (Tab.5) can be considered to include two parts. The first part is the basic information of the elderly person who they are assisting: name, relationship to the elderly, frequency of caring the elderly, profession and organization. The second part consists of duty and responsibility, knowledge of the issues, available resources and constraint. From duty and responsibility, designers will know the level of engagement of the care provider, and areas they should focus on. Knowledge of the issue allows designers to understand the capability of the elderly, and to some degree, the quality and validity of the services provided by the care provider. Available resources let designers know what kinds of resources they can possibly utilize, which can be potential opportunities of this design. Constrains will be something that the design should avoid or solve during the design process.

The form of care providers' activity research (Tab.6) mainly focuses on the care provider's engagement in different activities. Designers simply needs to indicate whether the care provider participates in the activity or not, and it will be clearer if designers can also indicate how the care provider participates in the activity. Pain points are information that can be acquired during interviews or from observation. It is suggested that designers record every piece of valuable information that the test subject mentioned, point by point.

After finishing these two forms, the designer should fully understand the role and pain points of care providers that will be involved in their design

### 3.5.3 Research of Roommates

Roommates are the group of people living with the elderly, the targeted users of this study. Inevitably, roommates may share the bathroom with the elderly, which makes them the secondary users of the study. Hence, it is quite clear that roommates are important stakeholders and their needs need to be fully respected as well.

#### ***Roommate Research***

Name		Age		Gender	
Relationship to the Elderly		Do You Share the Bathroom with the Elderly?		<input type="checkbox"/> Yes <input type="checkbox"/> No <input type="checkbox"/> Other _____	
Pain Points					

**Tab. 7. Roommate Research**

The form (Tab. 7) is designed for collecting information of the elderly’s roommates. There are mainly two parts of the form: basic information and pain points. From basic information, designers will be able to know the name, age, gender and relationship to the elderly of the roommate. If the roommate is an elder person as well, it is suggested to conduct elderly research of the roommate as well. Also, it is important to ask whether the roommate shares the bathroom with the elderly or not. If they do share one single bathroom, then the roommate’s opinion will be highly important. The second part of the form is pain points, which can be obtained through



interviews or observation. Designers should record all pain points that they discover during the research.

With research of roommates, it will be assured that the basic needs of all users of the bathroom are well considered.

#### **3.5.4 Bathroom Space Research**

One of the key values of this study is seeing the bathroom as a whole system, instead of simple combination of different products. The benefits of the systematic design guideline include increasing the consistency of different products in the bathroom, providing support during the entire process of the elderly's bathroom activity rather than improving a single product. Designers will be able to enlarge their horizon of this problem, since they will consider the topic more comprehensively.

In order to achieve a holistic view of the bathroom, designers need to conduct the bathroom space research. During the research, designers will systematically study the bathroom and activities happening in the bathroom, with the help of the tools provided by this study, the template of bathroom space research.

## ***Bathroom Space Research***

Name	Activity
Floor Plan	Secondary View
Pain Points	

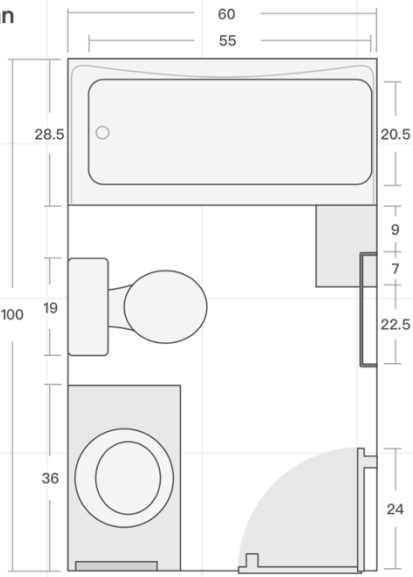
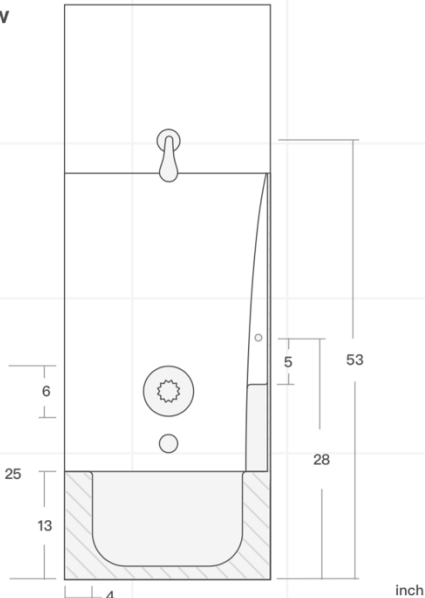
**Tab. 8. Bathroom Space Research Template**

Tab.8 is the template that will be used for bathroom space research. The first row of this template includes name and activity. Designers need to fill the name of the subject and the activity they are researching in these two blanks. The main portion of the template is the floor plan and secondary view. Designers need to draw the floor plan of the bathroom, with simple but understandable measurements of the appliances in the bathroom. The secondary view is optional, and designers can choose to draw it if they consider the floor plan as not explicit enough to present the activity that they are focusing on. Light grey lines are also provided for the convenience of drawing. After finishing the two drawings, designers need to indicate the problems that they



discovered in the drawing and explain them in words in the last row of the template. Below is a demonstration of the use of the template, and each step will be introduced clearly.

### ***Bathroom Space Research***

<b>Name</b> John Smith	<b>Activity</b> Bathing
<b>Floor Plan</b> 	<b>Secondary View</b> 
<b>Pain Points</b>	

**Tab. 9. Bathroom Space Research Example - Step 1 & 2**

Tab. 9 illustrates the first and second step of bathroom space research.

Firstly, designer needs to fill in the name of the elderly person, such as John Smith, and the activity they are researching, such as bathing.

Secondly, designers should draw the horizontal floor plan of the bathroom, and they can choose to use neutral colors to indicate the details of the floor plan. It is important to point out the size of appliances in the bathroom, as well as the units. Nonsignificant details do not need to be put in the drawing in order to keep the floor plan clean. For example, if designers are studying

bathing in this demonstration, then they may not need to indicate the size of the cabinet on the wall, since the elderly will not use the cabinet during the bathing activity. In other words, features related to the activity that designers are researching need to be clearly measured and comprehensively marked. Also, if a designer thinks the floor plan is not explicit enough to describe the activity, they are free to draw a secondary view, such as the vertical view of the bathtub in this demonstration. Designers can even employ more copies of the template if they need a third or even fourth view.

### ***Bathroom Space Research***

<p><b>Name</b>    John Smith</p>	<p><b>Activity</b>    Bathing</p>
<p><b>Floor Plan</b></p> <p style="text-align: right;">inch</p>	<p><b>Secondary View</b></p> <p style="text-align: right;">inch</p>
<p><b>Pain Points</b></p>	

**Tab. 10. Bathroom Space Research Example - Step 3**

The third step (Tab. 10) of using the template is explaining the route and the area of activity.

For example, in the floor plan, the area of undressing, bathing, dressing and hair drying are all indicated in light blue, as well as the route of the elderly's movement. Notes are also provided in order to explain the marks. From this step, designers will be able to know the process of the activity, and the blue areas also imply the space the designers should specifically consider when they are designing the bathroom.

### **Bathroom Space Research**

<p><b>Name</b> John Smith</p> <p><b>Activity</b> Bathing</p>	<p><b>Activity</b> Bathing</p>
<p><b>Floor Plan</b></p>	<p><b>Secondary View</b></p>
<p><b>Pain Points</b></p>	

**Tab. 11. Bathroom Space Research Example - Step 4**

Tab. 11 demonstrates the fourth step of using the template, which is identifying the areas that the elderly will mostly interact with. Green will be used for convenience of distinguishing this step from the previous ones.

In order to accomplish this step, designers should point out the areas, such as features of the appliance and details of actions in the environment, that the elderly will frequently interact with, such as touch, grasp and adjust. It is important to describe the area in detail, and use notes to explain the behavior of the elderly. From the combination of step three and step four, designers will understand the behavior of the elderly person, and the relation of them and the bathroom systematically, comprehensively and in depth.

### **Bathroom Space Research**

<p><b>Name</b> John Smith</p> <p><b>Activity</b> Bathing</p>	<p><b>Activity</b> Bathing</p>
<p><b>Floor Plan</b></p> <p>60 hold &amp; shampoo 55 20.5 28.5 9 7 22.5 100 19 36 24 inch</p>	<p><b>Secondary View</b></p> <p>adjust water direction 04 adjust faucet 6 hold while transferring 25 13 4 28 5 53 shampoo hold push stopper inch</p>
<p><b>Pain Points</b></p> <p>01 John needs to hold the edge of the bathtub when he is moving, but the edge is too low, and is always too slippery for holding.</p> <p>02 John needs to bend himself down in order to reach the stopper, which is a difficult and dangerous movement for him.</p> <p>03 When John is dressing and undressing, he almost has nothing to grasp except the towel rack.</p> <p>04 Because of the height of the faucet, it is impossible for John to adjust the direction of water.</p> <p>05 It is hard for John to adjust the faucet and measure water temperature when he is outside of the bathtub.</p>	

**Tab. 12. Bathroom Space Research Example**

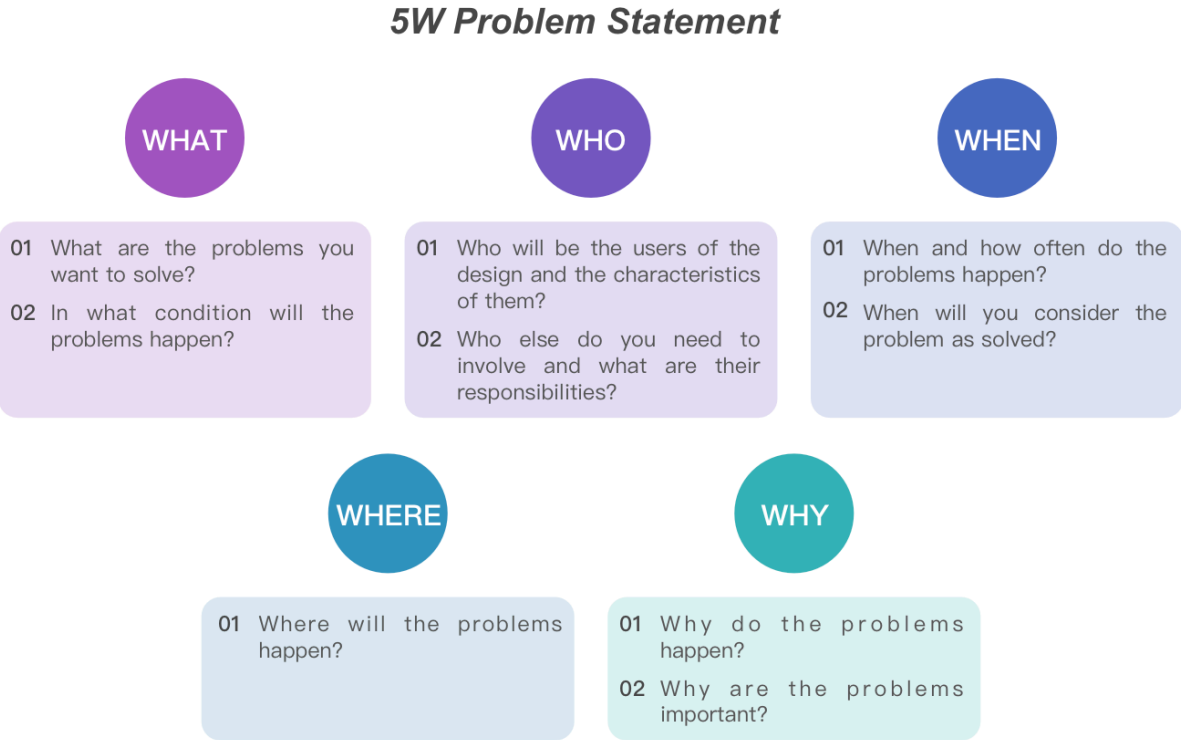
Tab. 12 shows the last step of using the template. Based on previous research and the map of the elderly behavior in the bathroom, designers can point out the places that the elderly are most likely to fail. It is suggested to number these discoveries, and designers should explain each point

clearly in the last row of the template. The form of finishing this bathroom space research is not limited. Designers can either choose to draw it by hand or work on it digitally.

After finishing bathroom space research, problems that designers discovered in previous research will not stand alone. Instead, those discoveries will be closely related to the bathroom environment in a straightforward way, and designers will acquire an in-depth understanding of the relationship between the environment and the users, which will be extremely helpful for further design.

### 3.6 Problem Statement

The problem statement will be the last step of the preparation process. In order to move ahead to the next ideation process, designers need to clarify the design problem that they discovered by utilizing the 5W problem statement approach below.



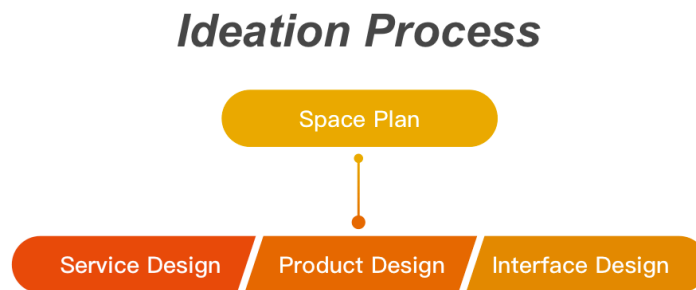
**Fig. 16. 5W Problem Statement Approach**

There are five topics in the 5W problem statement approach: what, who, when, where and why. Designers need to recall their research and reply to the questions under the five topics. From the proposed questions, designers will be able to pull information from research and organize it. Goal of the design, primary users, stakeholders, location, time, condition and in depth meaning of the issue will all be discussed in this approach.

After the problem statement, designers will achieve an explicit and comprehensive perspective of the problem, and groups will also obtain a unified and consistent view of the design problem, so that they will be able to advance to the ideation process successfully.

### 3.7 Ideation Process

The aim of this study is not simply designing the appliances in the elderly's bathroom, but to consider the bathroom space, elderly's activity, and appliances as a whole. Hence, there are four aspects designers need to consider during the ideation process: plan of the space, service design, product design and interface design.



**Fig. 17. Ideation Process**

During ideation, designers should firstly arrange the space of the bathroom, so that they will be able to identify the space, direction and placement of each zone. After that, they will design the services provided by the design, functions embedded in the design, tangible products, digital and physical interfaces. There does not exist a strict sequence among service design, product

design and interface design. Designers can keep improving the latter three design aspects until they have met the six principles, mentioned above and discussed below. The definition and content of each ideation process will be introduced in below sections.

### **3.7.1 Space Plan**

Definition:

The design and plan of the bathroom space. Creating a space plan is a prerequisite process.

Design Content:

- a. Define the area for each activity and clarify the route among all activity areas.
- b. Define the location of each product and clarify the route among all products.
- c. Define the configuration and direction of each product.

### **3.7.2 Service Design**

Definition:

The design of services that will be provided by and functions that will be embedded in the design.

Content:

- a. Clarify the function built in the design.
- b. Clarify the services that will be provided by the design.
- c. Clarify stakeholders that will be involved in the design, define their responsibilities, and design the method of getting them engaged.
- d. Consider different use scenarios and design for each stakeholder.

### **3.7.3 Product Design**

Definition:

The design of tangible product.

Content:

- a. Design the appearance of the product, such as colors, shapes and sizes.
- b. Consider the production of the product, such as materials and manufacture technologies.
- c. Consider different use scenarios and make sure that the design functions under all conditions.

### **3.7.4 Interface Design**

Definition:

The design of both digital screen-based interfaces and physical interfaces.

Content:

- a. Design the style of visual features, such as colors, fonts and icons.
- b. Clarify the content that will be delivered by interfaces.
- c. Consider other forms of information delivery besides visual information, such as voice information, according to different use scenarios.

## **3.8 Smart Bathroom Design Principles Considering the Senior Population**

During the ideation process, designers are required to follow the six design principles that are specifically proposed for compensating for elderly person's inabilities, fulfilling their needs in the bathroom and increasing their autonomy in a satisfactory way. These six principles have taken into account all of the topics that are discussed in the literature review, such as their physical,



sensory and cognitive impairments, their acceptance of technology, their difficulties in the bathroom, and the advantages and limitations of smart home technology.

## ***Smart Bathroom Design Principles Considering the Senior Population***

### **01 Discoverability**

Users should be able to locate and perceive information of the design easily, regardless of the condition of the user and the form in which the information is delivered.

### **02 Accessibility**

The design and its functions and services should be accessible to all users, including users with disabilities, in all conditions, including emergent conditions.

### **03 Understandability**

The design has taken users' experience, behavioral and cognitive habits into consideration. Users should be able to understand and operate the design easily or even intuitively.

### **04 Flexibility**

The design should accommodate users' diverse needs. The design should also meet each elderly user's changing needs as they get older. In different ways of achieving flexibility, users will have different levels of control of the design.

### **05 Simplicity**

Eliminate unnecessary functions and information. Reduce the users' burden of using the design by keeping it simple.

### **06 Reliability**

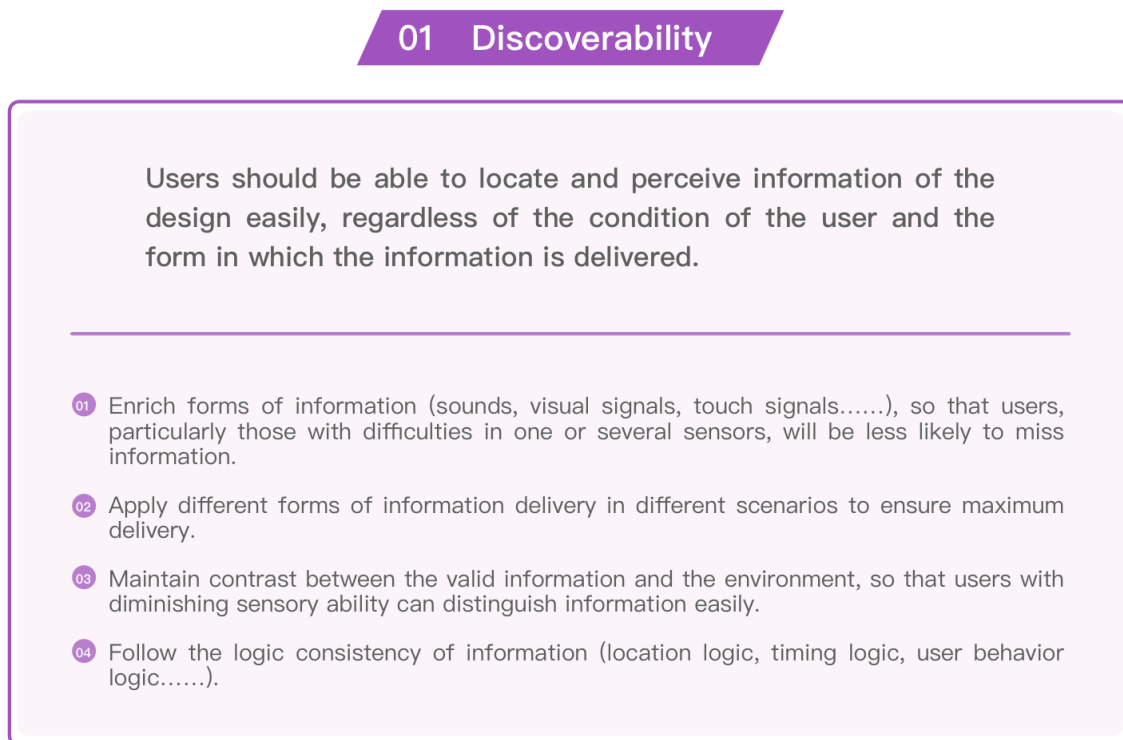
The design should behave in a trustworthy way and minimize the likelihood of failing.

**Fig. 18. Smart Bathroom Design Principles Considering the Senior Population**

The smart bathroom design principles (Fig. 18) include discoverability, accessibility, understandability, flexibility, simplicity and reliability. In the following section, this study will introduce the definition and guidelines of each principle respectively.

### 3.8.1 Discoverability

Fig. 19 presents the definition of discoverability and four guidelines that are provided to achieve it:



**Fig. 19. Discoverability**

Discoverability requires the design to convey information in a way that can be easily discovered and perceived by the users. Discoverability should be maintained in all conditions, no matter the conditions of the bathroom environment, such as the changes of brightness and noises caused by the running water. For the elderly users, who may have impairments in sensing information, designers need to be particularly careful to lower the barrier of information perception.

Considering elderly users who suffer from different level of sensory impairments, the first guideline suggests designers to enrich the form of information, such as combining visual signals and voice signals, so that users with visual disabilities are will able to discover information through their ears.

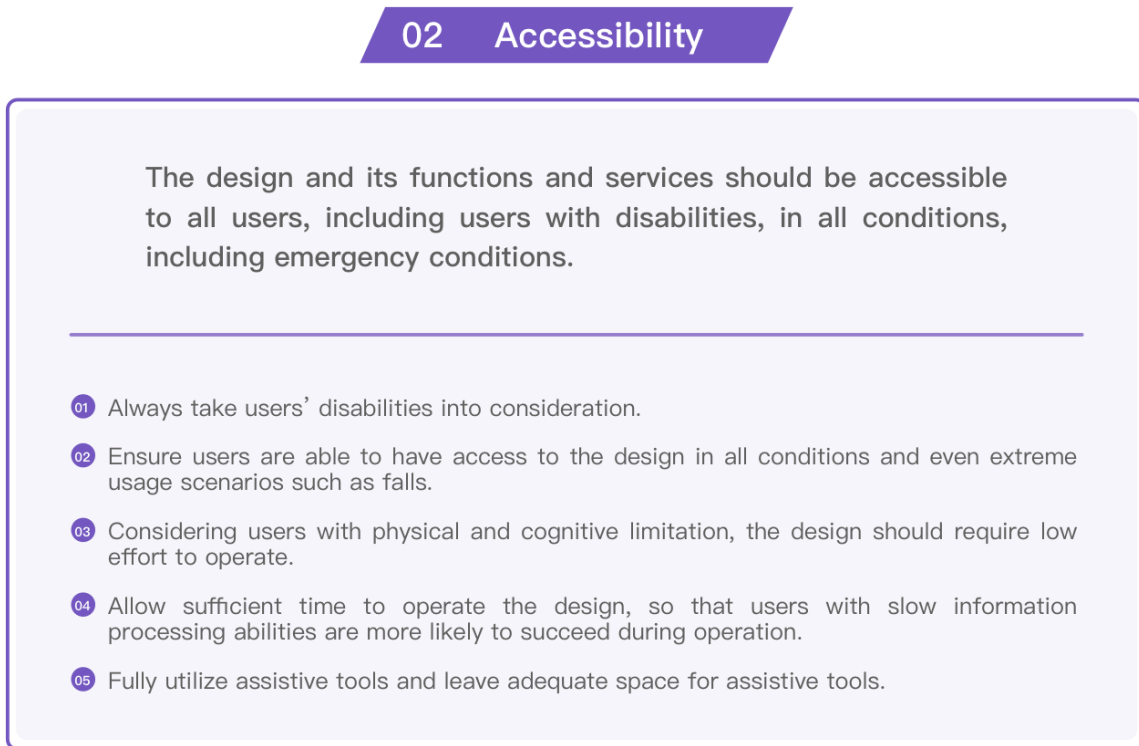
Although the form of information delivery is enriched, designers still need to consider the condition in which different forms should apply, which is the meaning of the second set of guidelines. Conditions that designers should take into consideration include environmental conditions and the activity of users. For example, when there are noises in the bathroom, voice signals will not be a perfect choice, and when the user is washing his/her hair with eyes closed, visual signals should not be selected.

The third guideline suggests increasing the contrast of the information and the bathroom environment, such as using colored signs in a white bathroom, so that users will be able to distinguish the information easily.

Designers also need to respect the objective logic of information, such as designing features around users according to the frequency or sequence of use, so that uses will be able to follow the logic of information naturally.

### 3.8.2 Accessibility

Fig. 20 presents the definition of accessibility and five guidelines that are provided to achieve it:



**Fig. 20. Accessibility**

Accessibility is one of the most fundamental principles. The design and its features need to be easily accessible to users, which means users should be able to obtain and operate the design effortlessly. This study has proposed five guidelines in order to help designers put this principle into practice.

Firstly, designers need to consider users' disabilities, especially physical disabilities and sensory disabilities. According to previous research, among all sensory disabilities, visual and touch impairments should be paid most attention to.

Secondly, designers need to be considerate, taking all possible use scenarios seriously. For example, the design might respond to accidents such as falling, allowing users to operate the design even when they are lying on the ground.

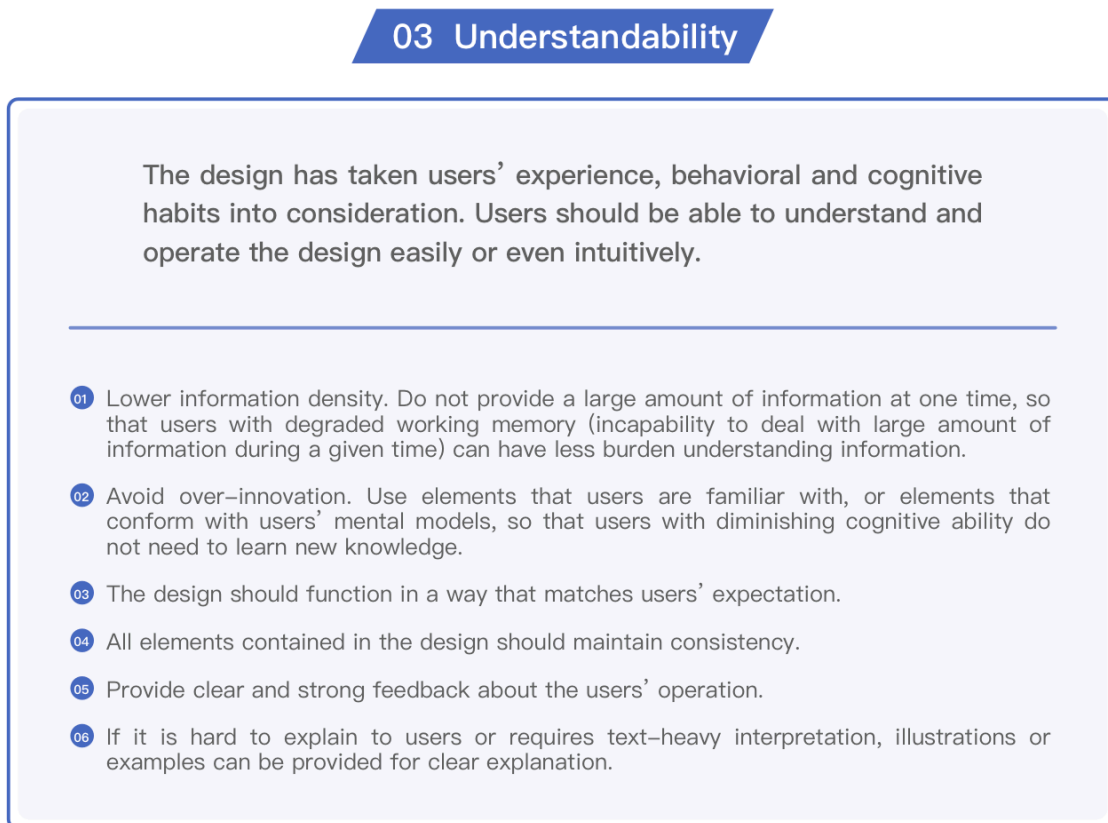
Thirdly, considering the degrading physical and cognitive ability of the elderly, and the existence of diseases such as arthritis and MCI, the design should require low effort to operate. For example, the designers should require half of the operation strength by young users because of the limited hand strength of the elderly, and provide users with prompts of what they should do in the following step to lower memory burdens.

Fourthly, elderly users need more time to learn new knowledge, which is one of the phenomena of cognitive degradation, so the design should provide users with sufficient time to operate, and not exert unnecessary pressure to users.

Lastly, elderly users are very likely to carry an assistive tool with them, such as a cane or wheelchair. Given the existence of assistive tools, the design should be accessible even when users are sitting on wheelchairs or walking with canes. In addition, the design itself can contain assistive equipment to give users extra help to operate the design.

### 3.8.3 Understandability

Fig. 21 presents the definition of understandability and six guidelines that are provided to achieve it:



**Fig. 21. Understandability**

The goal of understandability is letting users understand the design in the way that designers want them to, which means users have understood the design correctly and are able to operate it successfully. In order to achieve it, designers need to respect users' experience of using products, and follow the behavioral and cognitive habits of users. Below are the proposed guidelines in order to achieve understandability.

Degradation of one's working memory is one of the signals of being old, and the symptom of that is the incapability to deal with large amount of information in a short period. In order to design the smart bathroom understandably, information density should be lowered, so that users'

burden of comprehending the design will be relieved. For instance, designers can simplify the design by breaking heavy-text explanation into pieces, so that it will be more understandable for users.

Secondly, designers should select design patterns that are commonly applied and avoid over-innovation. For examples, triangle is commonly utilized to indicate directions, and designers can select triangles when they are trying to indicate directions. It is also a matter of respecting users' experience and mental models. By using familiar elements, the elderly do not need to learn new knowledge, and the design will be intuitively understood.

Thirdly, the design could be able to learn the behavioral mode or mental mode of users by recording and analyzing the history of use, and then the design would be considered to be personalized for each user. In this condition, the design will be a step earlier than users, and get everything prepared for them. In other words, the design will understand users.

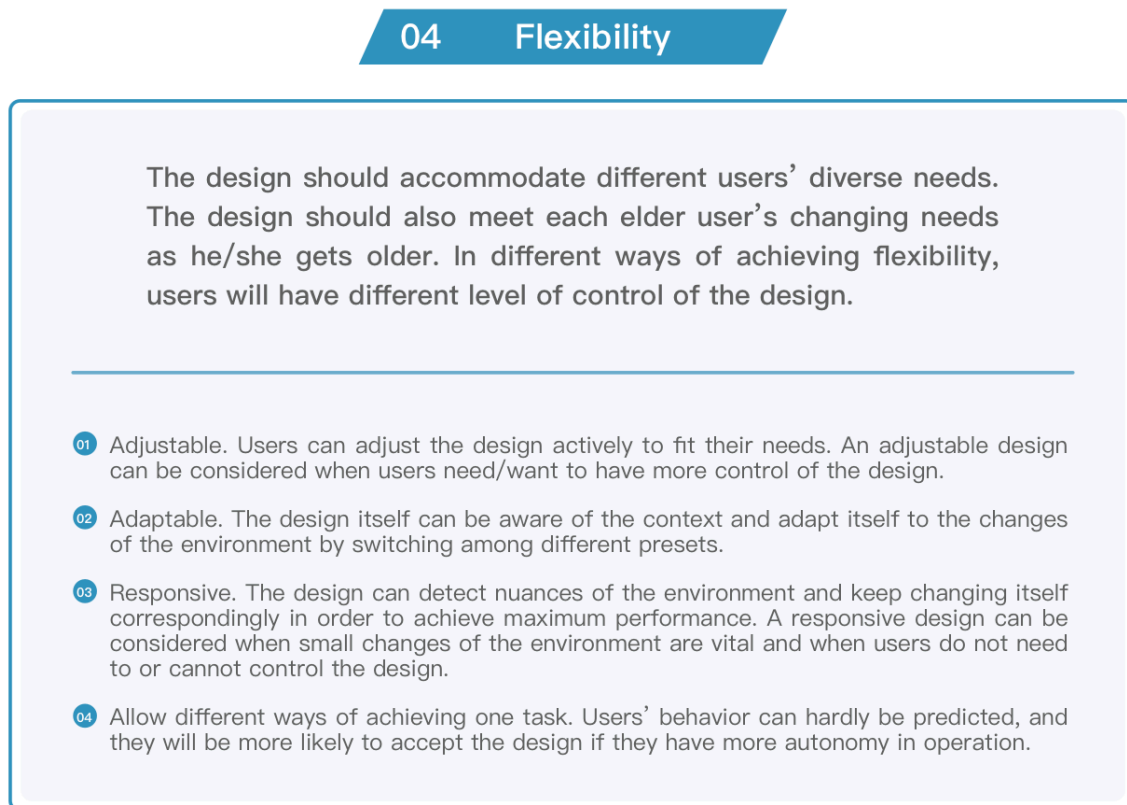
In addition, consistency of all design elements in the bathroom can definitely help with understandability. Rather than being forced to remember the meaning of each design elements, users just need to understand the design language one time, such as consistent color codes and same shapes for operable features.

Also, the design should always provide feedback to users in time, which will help users understand whether they operate the design right or not. If yes, it will increase users confidence in dealing with the design, and if no, feedback should give users tips or instructions of correct operation, which is even more necessary. Considering characteristics of the elderly, the feedback should be strong and clear to achieve maximum understandability.

Lastly, when heavy-text is inevitable, designers can choose to utilize graphics, or give examples of operation to interpret the design for users.

### 3.8.4 Flexibility

Fig. 22 presents the definition of flexibility and four guidelines that are provided to achieve it:



**Fig. 22. Flexibility**

The condition of the primary user of this study, the elderly, is changing slowly but continuously during the aging process. Also, other users, such as roommates, may also use the bathroom, who may have totally different body condition from the elderly users. Hence, it is really necessary to make the design flexible, so that it can accommodate the changing needs of different users. Also, being flexible means users will have more control of the design so that they can change the design into the way that they prefer, which is one of the key requirements of successful acceptance of new products.



There are three levels of flexibility: adjustable, adaptable and responsive, which will be introduced below:

Adjustable means users can adjust the design actively and manually to fit their needs, such as changing the height of seats in order to seat comfortably. The benefit of adjustability is being able to control the design entirely, however, it requires the most energy and may not be the perfect choice for users with limited motor function.

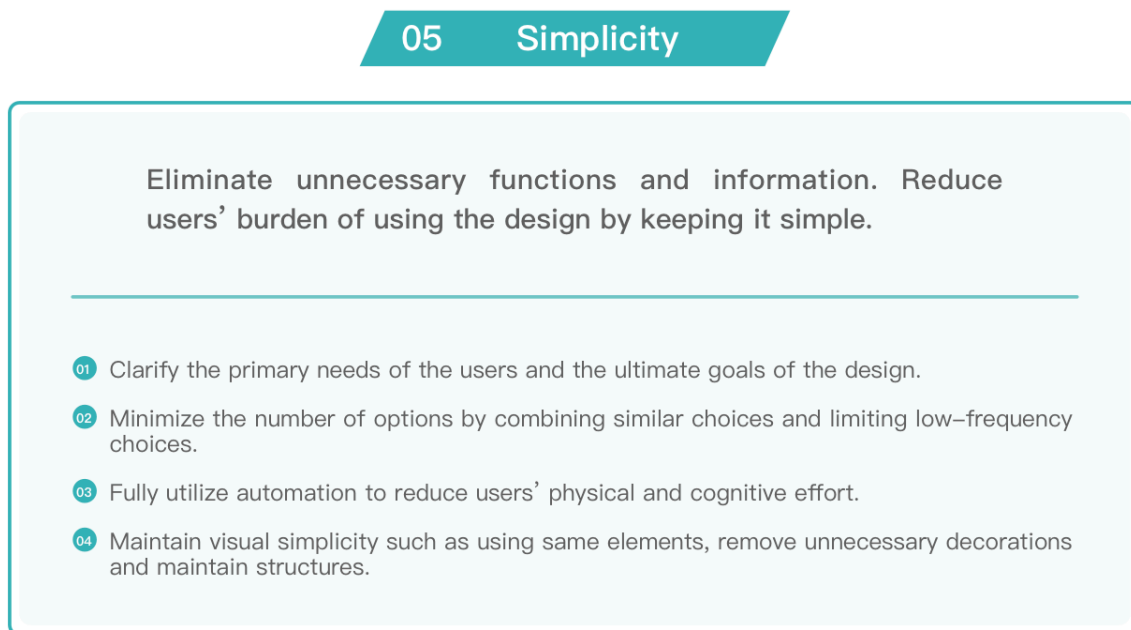
When a design is adaptable, there always exists several presets that can meet users' needs. As the environment changes, the design will switch among the presets to maintain the best performance. In some cases, users are able to change from one preset to another actively as well, which can be considered a combination of adjustability and adaptability.

Responsive designs are highly sensitive to their context. They can detect the nuances of the environment and change themselves accordingly. User controls are hardly seen in a responsive design; instead, the design can make its own decisions. Both adaptable design and responsive design respond to the environment, and the difference between them is that responsive design does not have presets, but is changing constantly.

Besides these three modes of flexibility, the design should also allow users to finish the task in their preferred ways, such as not requiring a strict consequence to the end, which also give users more flexibility.

### 3.8.5 Simplicity

Fig. 23 presents the definition of simplicity and four guidelines that are provided to achieve it:



**Fig. 23. Simplicity**

According to the literature review, an ideal bathroom should be function-efficient, which means the bathroom should provide services that are most needed, and avoid complexity, so that the elderly will receive what they indeed need without the burden of utilizing the design.

In order to fulfill simplicity, clarifying the goal of the design is really fundamental, which means designers need to follow the conclusions they have come to during the problem statement process, and do not design the project based on their imagination. Instead, every feature they add to the design should be proved during the research process.

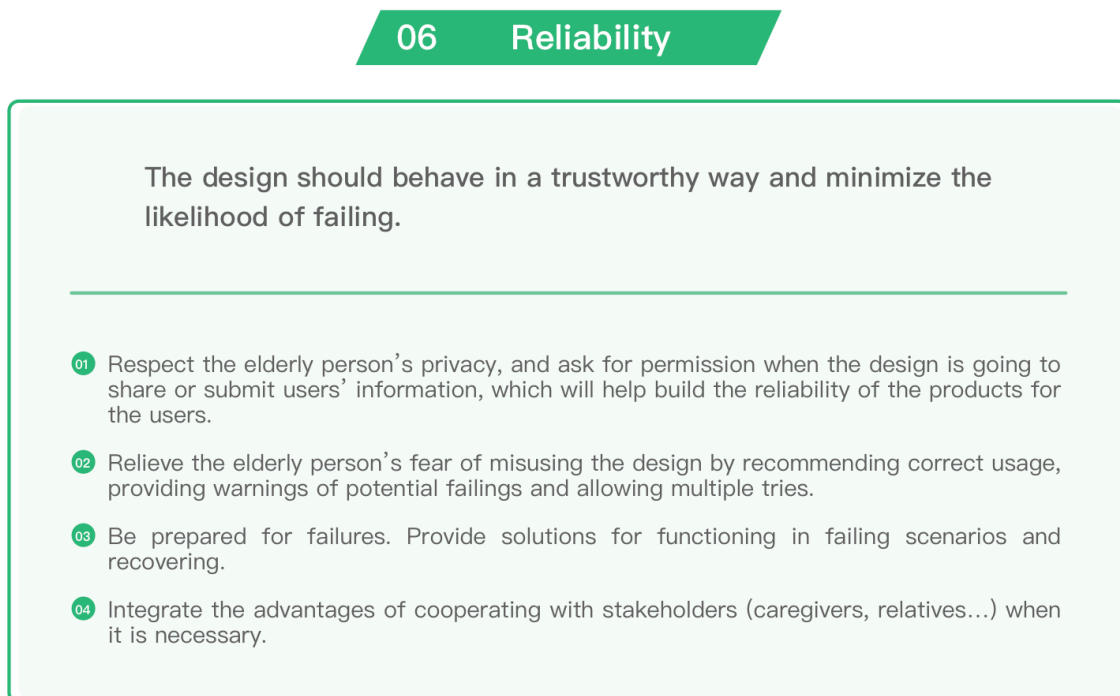
Also, while providing options for users, designers should minimize the number of choices to keep the design simple, such as combining similar choices.

Automation also makes the design simple. By automation, users do not need to operate the design by themselves. For instance, the machine will run with a simple press of the “start” button, which lowers the users’ burden significantly.

Visual languages of the design also have a lot to do with simplicity. By removing unnecessary details of the design, users will be able to enjoy a visually simple product, and can also distinguish information that is supposed to be delivered by the product easier.

### 3.8.6 Reliability

Fig. 24 presents the definition of reliability and four guidelines that are provided to achieve it:



**Fig. 24. Reliability**

Considering the special characteristics of the elderly, and their unfamiliarity with smart home products, designers need to build reliability between users and the design, so that users will have less psychological burden and be more willing to adopt new products.

To be reliable, the design needs to respect users' privacy of personal data. For example, designers should let users know what kinds of data are collected and what they are going to do with the data. Further, if data is being sent to a third party, the design should ask users for permission. By being respectful of users' privacy, reliability between them will be gradually built.

Also, according to the research, one of the reasons that the elderly refuse to use new products such as smart home products is a fear of breaking them. Hence, it is necessary that the design should indicate the right operation method of the design, such as providing friendly warning of potential fails.

No matter how complete the designer is, users may still fail during operation, and designers should have predicted these possibilities, such as unintentional damage caused by users, and inevitable environmental conditions like power outage. When users do not need to worry about malfunctions, their reliability of the design will be established.

Lastly, it is undeniable that some people trust humans much more than machines, and they insist to be assisted by caregivers rather than merely products. Although the purpose of this study is helping the elderly accomplish bathroom activities independently, considering their trust of people, it is better to integrate the advantages of both machines and a real person. Users should be able to choose if they prefer to be helped by real person.

### **3.9 Conclusion**

In Chapter Three, the approach of smart bathroom design for the elderly (Fig. 14) is proposed. The approach are divided into mainly two sections. The first part includes four preparation steps: problem discovery, problem identification, research and problem statement. Tools are provided in each step to help designers to achieve a satisfactory result in each step. The second part is the ideation process, which includes four design aspects, the content of design, and six design principles that need to be followed during ideation. The six principles are discoverability, accessibility, understandability, flexibility, simplicity and reliability, and guidelines of each principle are also provided to assist designers to put the guideline into practice. A complete design project will be delivered in the end of the ideation process, which is anticipated to have met the needs of users of the project, and fulfilled the six principles that are proposed for designing a smart bathroom for elderly users. It is suggested that designers should evaluate the design result in practice to check whether it has met the requirements that are proposed in the first stage or not, which will not be discussed in this study.

In Chapter Four, representative examples of each guideline proposed in the six principles will be introduced to illustrate the application of the guideline and prove the guideline further.

## **Chapter 4**

### **Demonstrations of the Smart Bathroom Design Guidelines**

#### **4.1 Overview**

In Chapter Four, representative examples of each guidelines proposed in the six principles will be introduced to verify the smart bathroom design guideline and provide designers with practical applications of this study. These examples come from existing smart home products in the market, and several examples are concept designs that are projected to be released in the following years. Considering the lack of smart bathroom products, examples in this chapter may be mainly used in the living room, bedroom, front door or in the whole home, not only in the bathroom.

There will be 26 examples in total, and each one will illustrate the topic. In the following section, this study will present these applications, and illustrations of each example will be provided as well.

## 4.2 Discoverability

Users should be able to locate and perceive information of the design easily, regardless of the condition of the user and the form in which the information is delivered:

1. **Enrich forms of information** (sounds, visual signals, touch signals.....), so that users, particularly those with difficulties in one or several sensors, will be less likely to miss information:



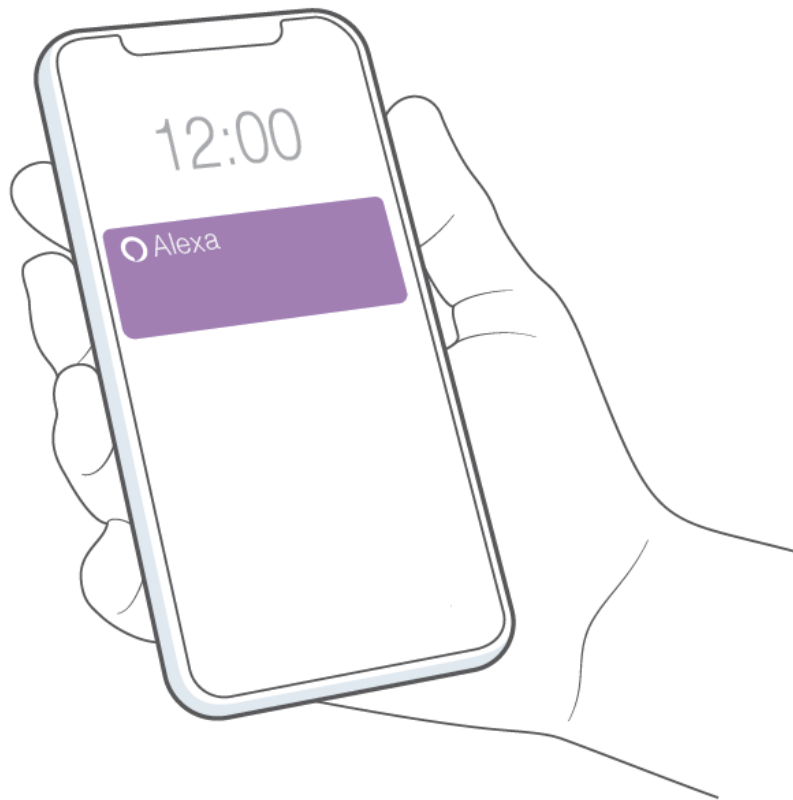
**Fig. 25. Amazon Echo and iPhone**

Amazon Echo, one of the most popular voice assistants in the market, provides three ways to transmit information: light, voice and notifications (Fig. 25). When having conversations with Alexa, the assistant built in Echo, Echo will make sounds and the light on the top rim of Echo will shine. With the integration of both voice and visual signals, even users with visual or hearing disabilities are able to know the functioning status of Echo. In some cases, Echo will send

notifications to users' phone, which is a combination of light, sounds and vibration, and can hardly be missed by users.

Similar mechanisms can be applied to a smart bathroom. For instance, when a smart bathtub is going to notify users that the bathtub is full of water, it can send information to users in the form of voices, lights and mobile notifications, so that users can hardly overlook it.

**2. Apply different forms of information delivery in different scenarios to ensure maximum delivery:**



**Fig. 26. Receive Notification from Amazon Echo**

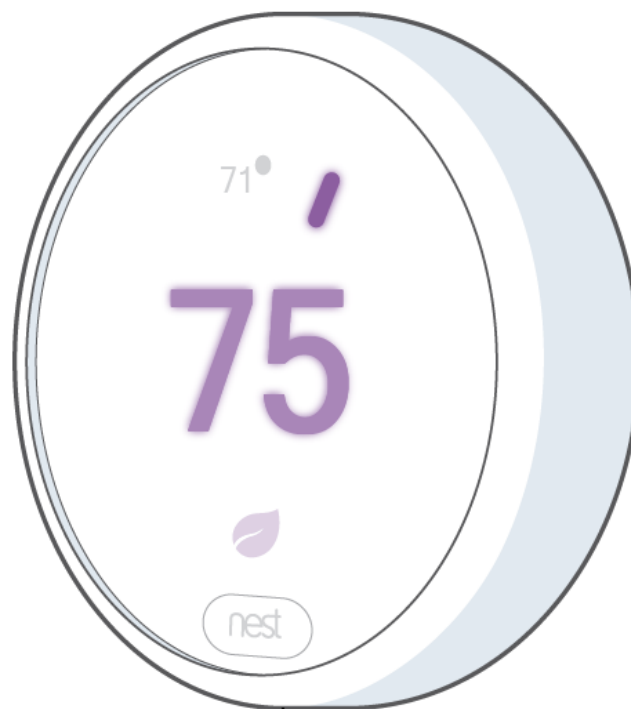
As introduced in the previous section, Amazon Echo provides three forms of information: light, voice and notifications. In most cases, such as having normal conversation with and making commands to Alexa, Echo will respond both with sound and a circle of shining light, so that users will be able to receive the signal clearly and discover that Echo is functioning. However, these



forms of information will be invalid if users are not near Echo. Hence, in other situations, such as the detection of gas leak or making a weekly order through Amazon, Echo will push a notification to users' phones (Fig. 26), so that users will not miss any information even if they are far from home.

Similar logic will work in a smart bathroom. For example, users can hardly open their eyes when they are washing hair, so a smart bathroom should deliver information in other forms when users are showering, such as voice signals.

**3. Maintain contrast between the valid information and the environment, so that users with diminishing sensory ability can distinguish information easily:**



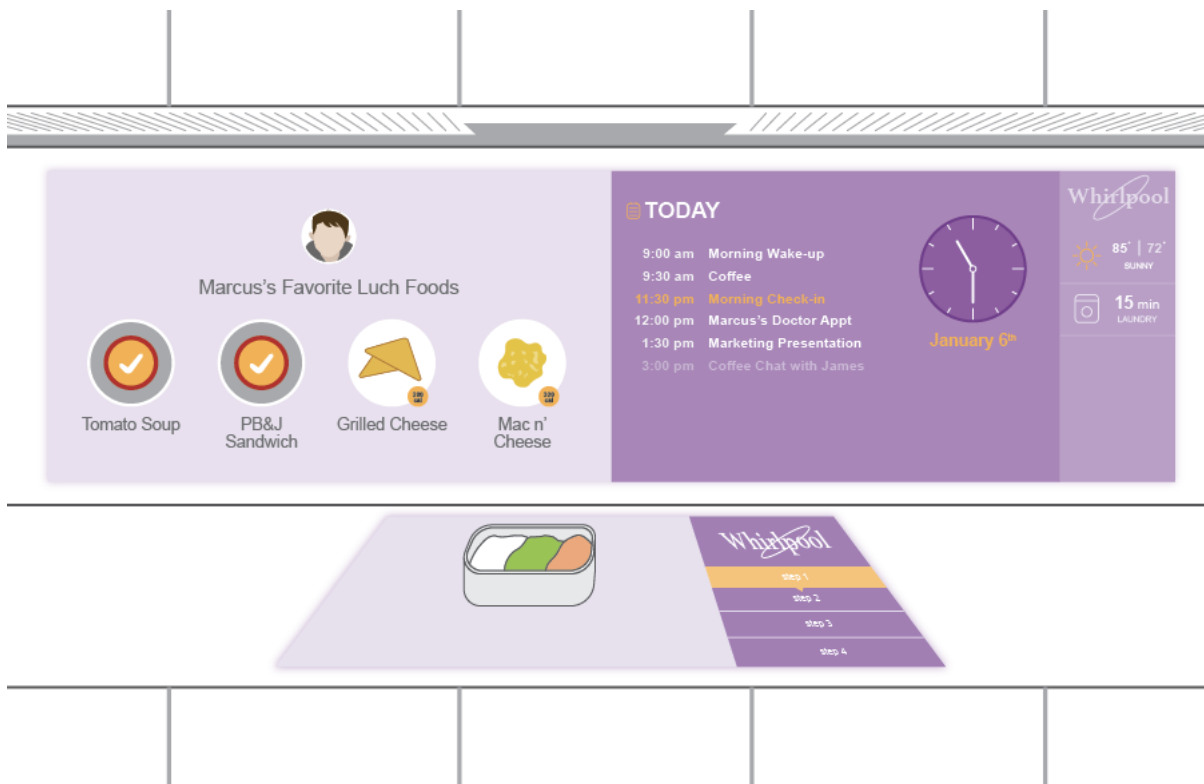
**Fig. 27. Nest Thermostat E**

Nest Thermostat E (Fig. 27) is a temperature sensor and controller. The visual interface of Nest Thermostat E is straightforward: the temperature in the home is presented on the screen in colored, big and bold font, making a perfect contrast to the neutral color background. With the

clear visual difference of the temperature and the background, users are able to discover information on the screen even with a certain distance. Due to color and size, secondary information, such as mode and logo, are not as conspicuous as primary information, temperature in the home, and users can see them only when they are standing close to the Nest Thermostat E.

Many bathrooms are painted in neutral background. Learning from the Nest Thermostat E example, functioning features such as screens and switches in a smart bathroom can be painted in colorful colors, so that the contrast between the background and valid information is created, and users will be able to discover useful information easily.

**4. Follow the logic consistency of information** (location logic, timing logic, user behavior logic.....):



**Fig. 28. Kitchen of the Future by Whirlpool**

In Whirlpool's design concept of kitchen of the future (Fig. 28), the wall and counter top of the kitchen are two screens, indicating the daily routine of the home owners and helping people to prepare meals step by step. Although there is a lot of information contained in the future kitchen, users can still easily discover information that they need. The reason for the easy discoverability is the logical arrangement of all information.

In the kitchen of tomorrow, information and tutorial of each task will be presented according to users' routine. For example, users have set the morning check-in at 11:30 pm, and the screen will display the guide for morning check-in automatically at 11:30 pm, which means information is delivered basing on timing logic. When tutoring users to finish each task, information will be presented step by step, which is delivering information based on behavioral logic.

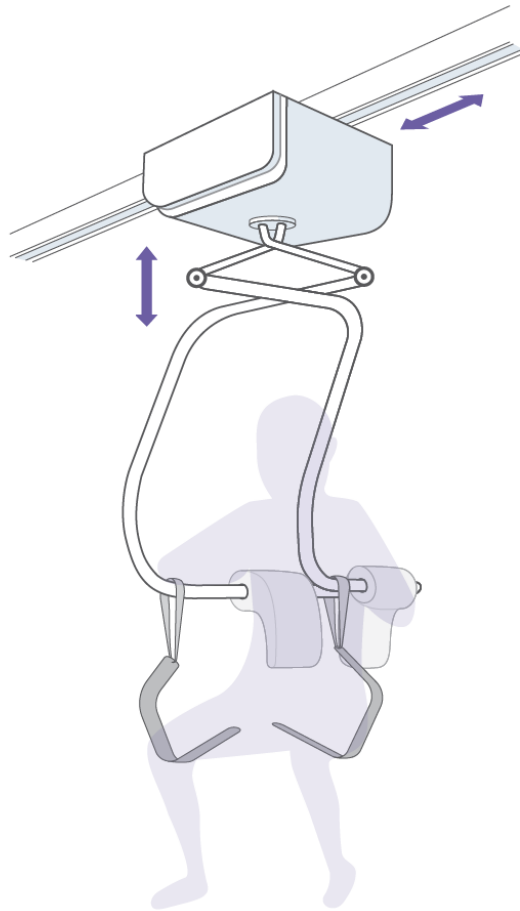
By presenting information logically, instead of requiring users to find information by themselves, designers are organizing and unfolding information just in front of users, so that they can discover information easily.

When designers are designing the process of assisting users to accomplish bathroom activities, they should also send out information according to the sequence of users' behavior, so that users can discover information that they need easily.

### 4.3 Accessibility

The design and its functions and services should be accessible to all users, including users with disabilities, in all conditions, including emergency conditions:

1. Always take users' disabilities into consideration:



**Fig. 29. The Transfer Equipment in the Smart Apartment  
for People with Disabilities at the Helen Hayes Hospital**

In Helen Hayes Hospital in New York, a smart apartment is designed for people with disabilities. In this apartment, residents with low capacity will be able to finish daily activities independently. The primary accomplishment of this apartment is ensuring residents can access everything they need in the apartment. For example, the apartment is built with wide doors to allow users with assistive tools go through them easily. Voice control is also built in the apartment so

that users can control appliances in the apartments easily with their voice. The apartment is even built with routes on the ceiling and transfer machines (Fig. 29), so that users with limited walking ability can move from point A to point B easily. In this example, designers have taken users' physical disability into full consideration so that no matter the degree of physical disabilities, residents will be able to live independently in this apartment.

When designing the smart bathroom for the elderly people, designers can learn from the Helen Hayes Hospital example. For instance, designers can make sure that users can move freely in the bathroom by leaving adequate space and assisting users along the path, and lower the effort to operate the design by utilizing voice control.

**2. Ensure users are able to have access to the design in all conditions and even extreme usage scenarios such as falls:**



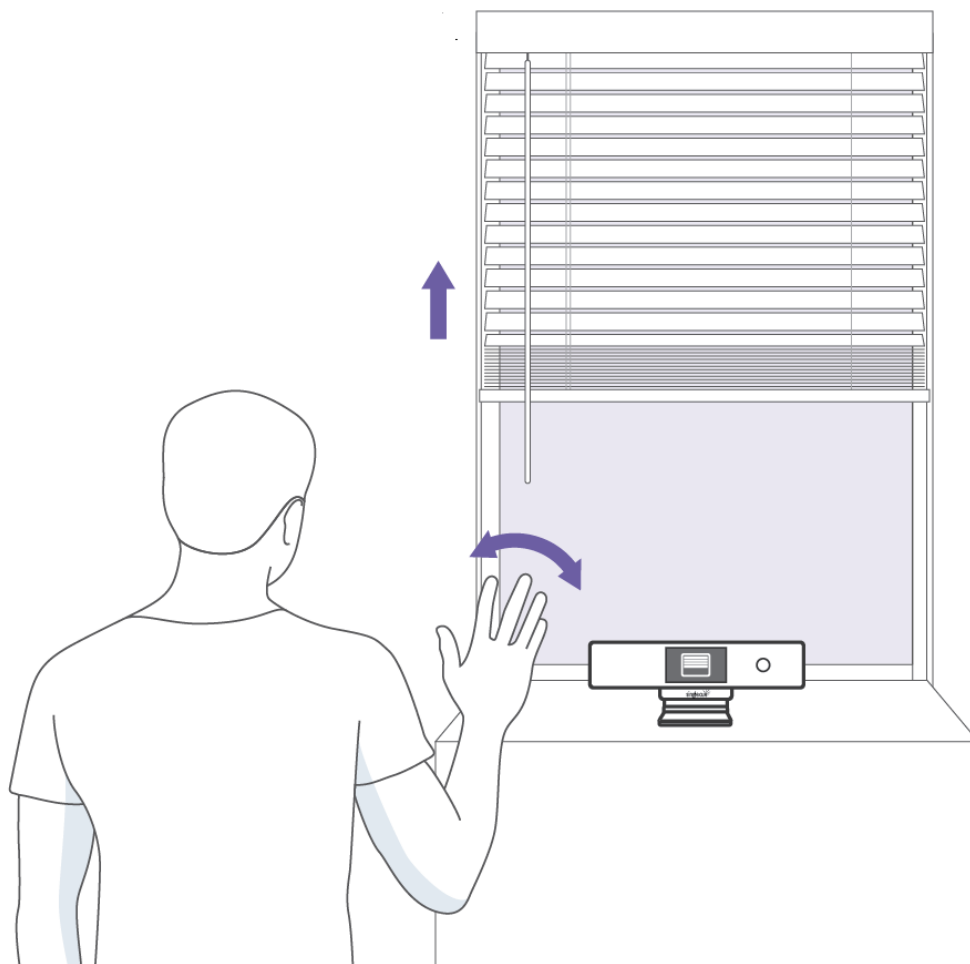
**Fig. 30. Philips AutoAlert**

Philips AutoAlert (Fig. 30) is designed for a person's falling, the most unwanted accident during aging. When AutoAlert detects a fall, it gives users 30 seconds to stand up. However, if the

person cannot stand up by their own, they will still have easily access to the “help” button on AutoAlert since it is hanging on their neck. In the most severe condition, if a person has lost consciousness, AutoAlert will make a call automatedly to a Philips Life Line consultant. In other words, even if a person has lost functioning abilities, AutoAlert will still function and ask for help for the elderly.

Similar products can be provided for the elderly users in a smart bathroom, so that even if they have fallen on the ground and lost consciousness, the design can help them by calling for help.

**3. Considering users with physical and cognitive limitation, the design should require low effort to operate:**



**Fig. 31. Singlecue**

Singlecue is a gesture control hub, which allows users to control home appliances with simple gestures. For example, after setting up the Singlecue system, users can open the blinds effortlessly just by waving their hands (Fig. 31). They do not need to walk to the window or stretch their arms to reach the blinds anymore, which will be a significant relief for the elderly with physical disabilities.

Changing the direction of the shower's faucet can be troublesome for the elderly people, because it is commonly mounted on a high position of the wall, and is difficult to reach. Inspired by Singlecue, this need can be easily satisfied if users can use gesture control to monitor the direction of the faucet.

**4. Allow sufficient time to operate the design, so that users with slow information processing abilities are more likely to succeed during operation:**

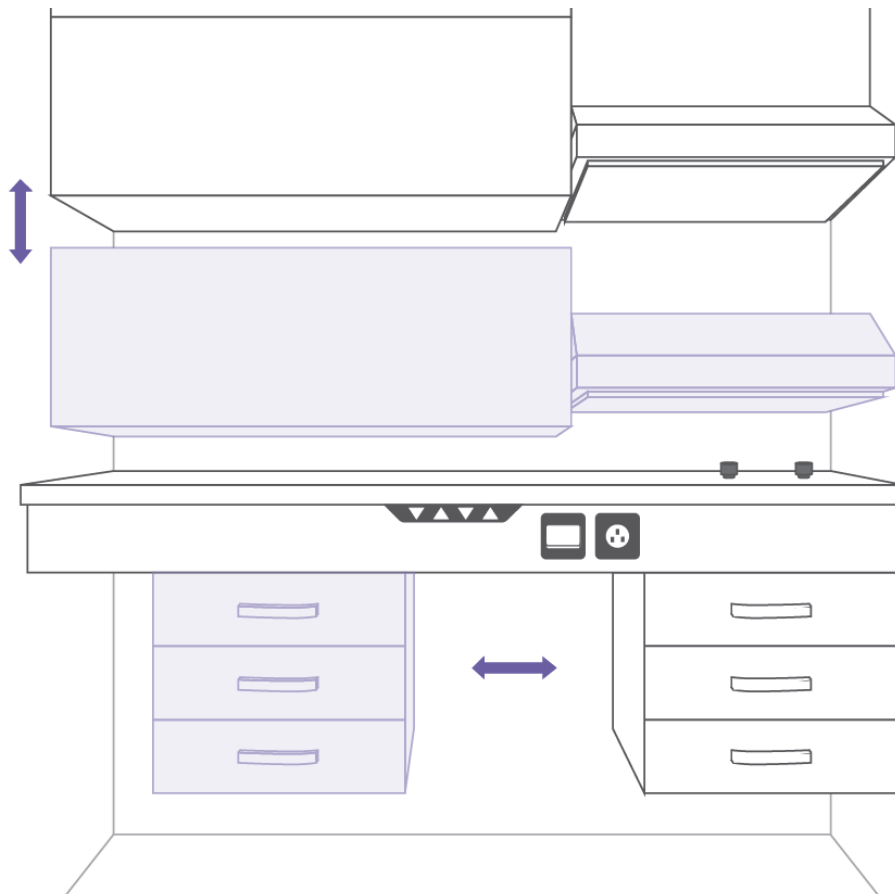


**Fig. 32. “Wait” Commands of Amazon Echo**

Amazon Echo allow users to build their own routine. For example, users can ask Alexa to operate task 1, 2 and 3 one by one just with one command. Now, users can also add a Wait command in a preset routine (Fig. 32). When a Wait command is inserted in a routine, echo will wait before beginning the next task, and users can take their time to finish tasks one by one.

The operation of smart bathroom, such as setting a preferred room temperature may take several steps, during which the design can leave adequate time for users to operate by allowing users to ask the device to wait, so that users do not need to be worried and will be more likely to accomplish the task.

**5. Fully utilize assistive tools and leave adequate space for assistive tools:**



**Fig. 33. The Wheelchair Accessible Kitchen**



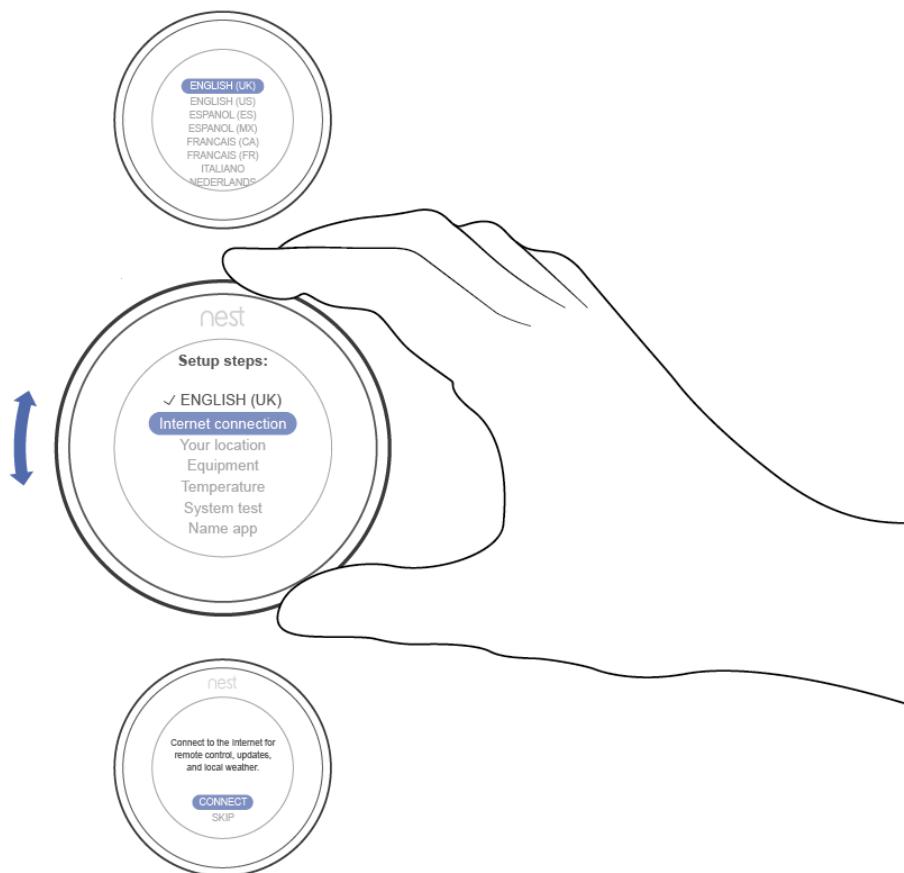
Fig. 33 presents a kitchen that is particularly designed for people on the wheelchair. All components of the kitchen, such as the table, cabinets and range hood, can be moved closer to users so that they can have easy access to whatever they want and be able to cook by themselves. This kitchen also leaves adequate space under the counter top so that users in the wheelchair will be able to move in and out.

Assistive tools are common among the elderly, and operation of the bathroom design should be accessible even when the elderly is accompanied with an assistive tool. Similar features of the kitchen in the example can be applied in a smart bathroom, such as height adjustable faucets and adequate space between different appliances.

#### 4.4 Understandability

The design has taken users' experience, behavioral and cognitive habits into consideration. Users should be able to understand and operate the design easily or even intuitively:

1. **Lower information density. Do not provide a large amount of information at one time, so that users with degraded working memory (incapability to deal with large amount of information during a given time) can have a lesser burden understanding information:**



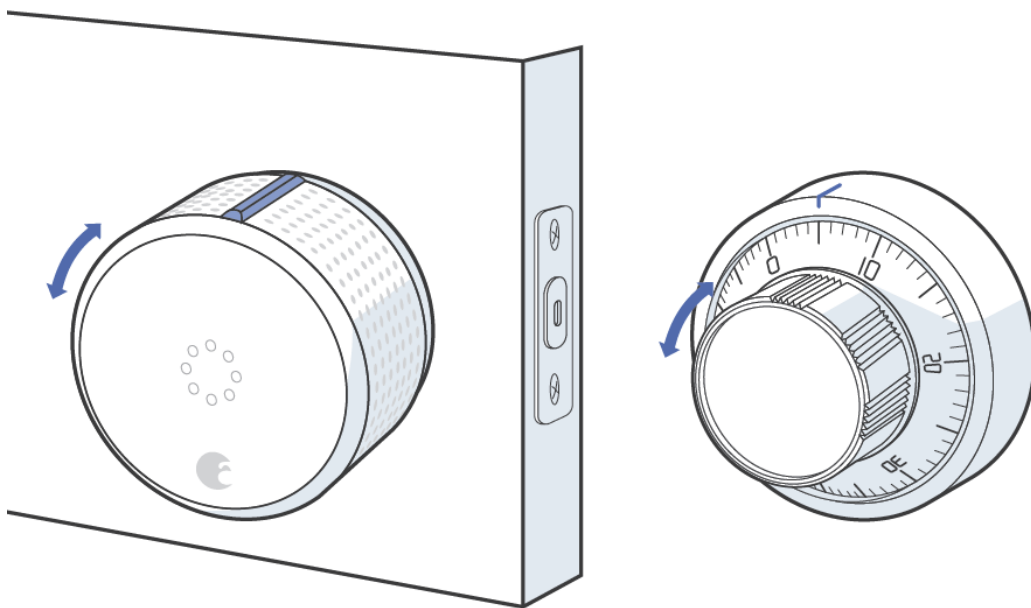
**Fig. 34. Installation Process of Nest Thermostat**

The installation process of Nest Thermostat can be problematic. Besides mounting Nest on the wall, the installation of the system mainly includes seven aspects: language, internet connection, location, equipment, temperature, test and name. As shown in Fig. 34, in order to lower

information density and increase users' understandability of the process, the installation of Nest is divided into seven small steps, and users will be guided to accomplish them one by one. With the proper design of the installation process, actually, users do not need to learn how to set the system up. Instead, they just need to follow the system's guidance and finish installation easily.

Similar design can be applied to the installation of smart bathrooms to lower the amount of information that is going to be delivered in one time, and users will be able to understand and accomplish installation process easier.

**2. Avoid over-innovation. Use elements that users are familiar with, or elements that conform with users' mental models, so that users with diminishing cognitive ability do not need to learn new knowledge:**



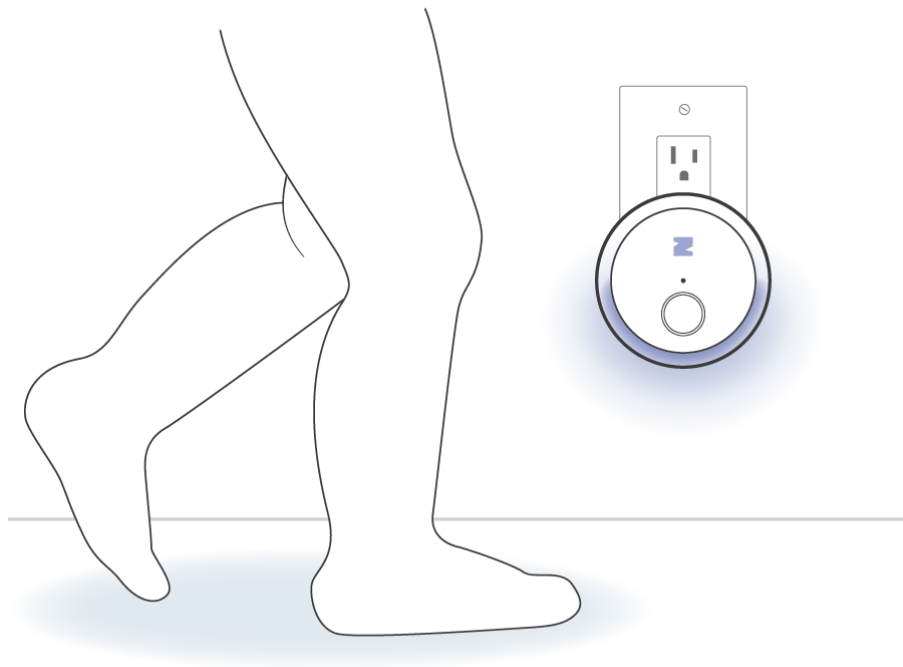
**Fig. 35. August Smart Lock and A Traditional Safe Box Lock**

A smart lock can be confusing: users are not familiar with the mechanism of the lock and they may even not consider it as a lock. However, this situation will not happen to August Smart Lock since it has inherited some representative features of a traditional lock. As shown in Fig. 35, the appearance of August Smart Lock shares some similarity with a lock of a traditional safe box,

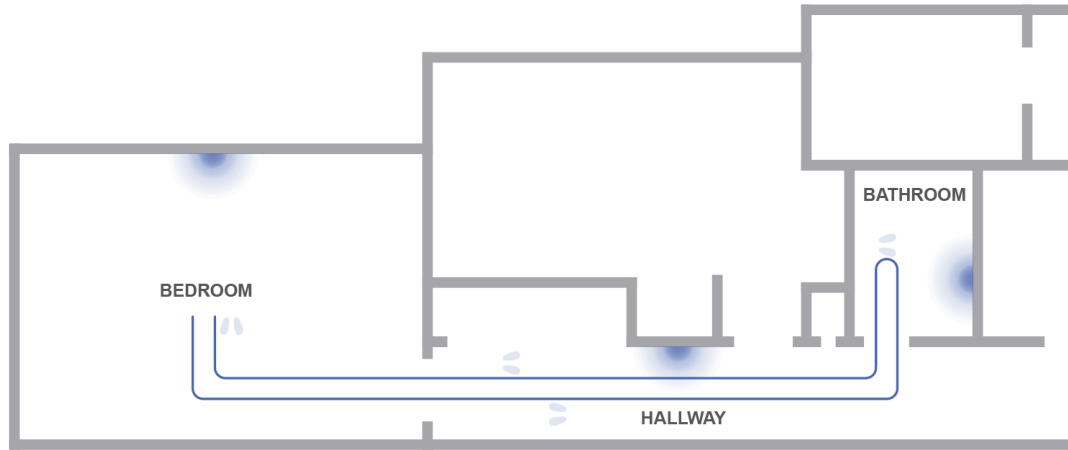
such as the code on the side of the lock and the line indicating the unlock position. For users who have never used the August Smart Lock, especially the elderly users, they can also simply understand that it is a lock according to their past experience.

When designers are designing the smart bathroom, no matter of the technologies that exist in the design, the appearance of the bathroom should maintain the traditional style, so that users will be more likely understand the product instantly based on their experience.

**3. The design should function in a way that matches users' expectations:**



**Fig. 36. Zing Learn and Predict User's Route at Night**

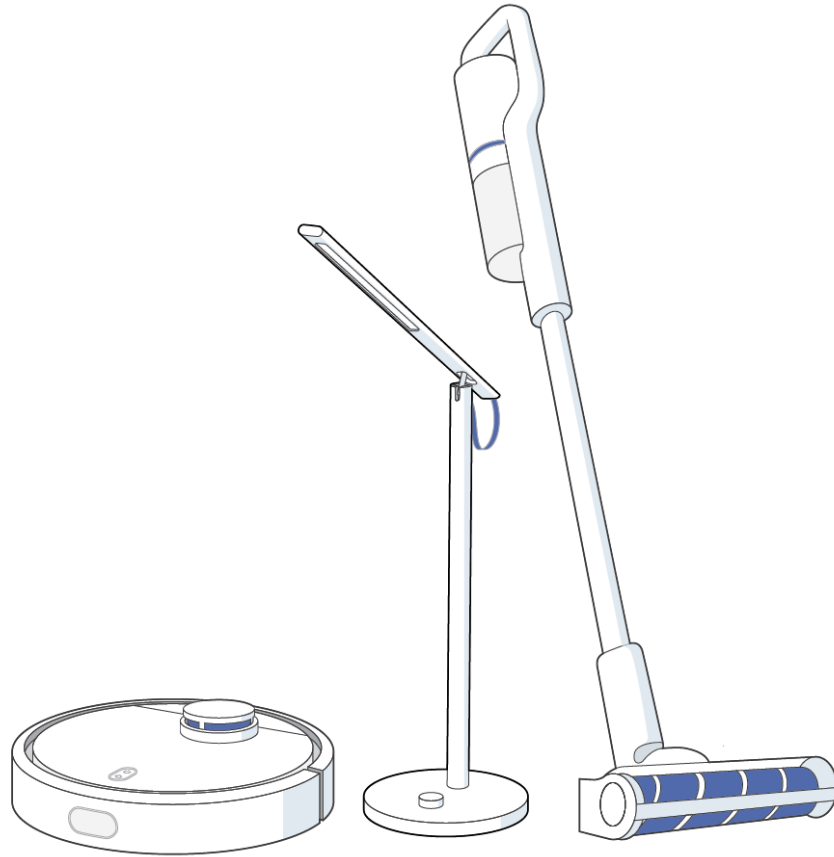


**Fig. 37. User's Route at Night**

Zing is a smart light that can record and analyze a user's routes at night. After studying the user's routes, Zing will be able to simulate those routes and turn on the light along the path automatically at night (Fig. 36, 37) when it detects the user's behavior. For example, it will turn the lights on the path to the bathroom on when the user just get out of bed, and the user can go to the bathroom directly and safely. In other word, the design can understand users actively, learn their behavior, and function automatically before users takes action. For users, the design will function in the way that perfectly match their expectation, which also lower their burden of understanding the design.

In a smart bathroom, for instance, the bathtub may be able to record and analyze users' preferred water temperature for bathing, and have the bath prepared in that temperature automatically, which means users will have a bath that meet their expectation, and they do not need to spend too much energy on adjusting water temperature and understanding the operation.

4. All elements contained in the design should maintain consistency:



**Fig. 38. Robot Vacuum, Smart Lamp and Vacuum Cleaner by Xiao-Mi**

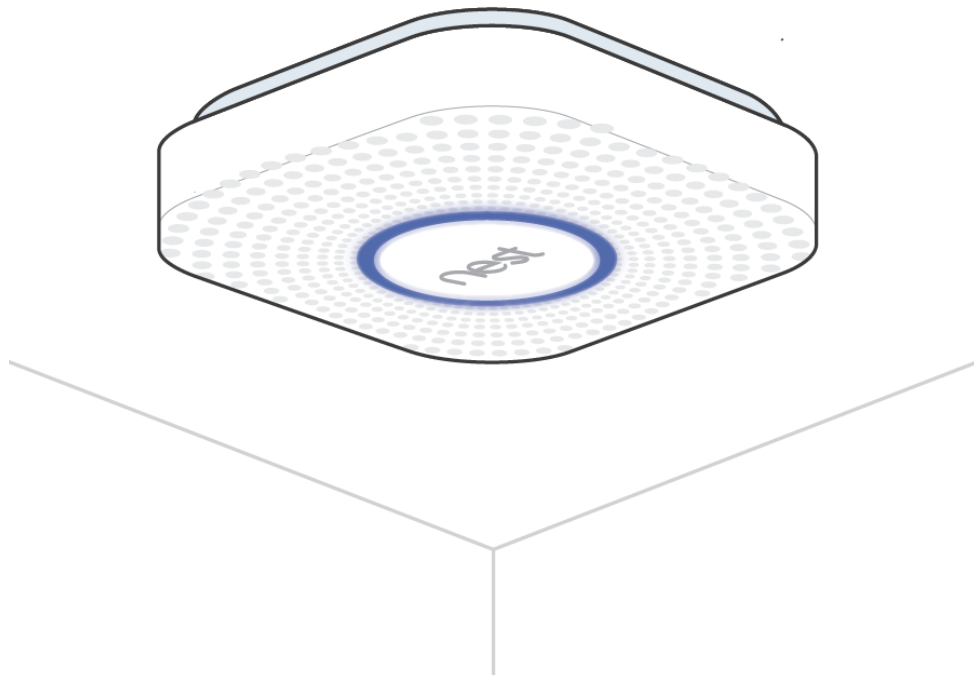
Xiao-Mi has produced a great number of smart home products, including smart appliances, smart lightening, smart air and water purifier, sockets and sensors, personal care products and entertainment devices, which mainly contains all smart home categories. Although Xiao-Mi is in many product categories, all products of Xiao-Mi are visually similar and are easy to understand once users get used to their visual languages.

Fig. 38 shows a smart vacuum, a smart lamp and a vacuum cleaner made by Xiao-Mi. As we can see from these three products, Xiao-Mi products utilize rounded features frequently, such as the lamp's big rounded arms and circular button of all products, which will make users feel softness and friendliness. Also, Xiao-Mi products share the same color codes. Xiao-Mi products

are mainly in neutral colors, but all functioning features, such as the replaceable brush of the vacuum cleaner, and the wire of the lamp and the laser distance sensor of the robot vacuum, are coded in the same color, which will help users to understand the usage of all products in Xiao-Mi smart home system easily.

The design of smart bathroom can learn from Xiao-Mi smart home products, painting all functioning features in obvious colors, so that users will be more likely to understand the operation of all appliances in the bathroom, once they are familiar with the color codes of the design.

**5. Provide clear and strong feedback about the users' operation:**



**Fig. 39. Nest Smoke Detector**

Just when users pull out the paper sealed on the Nest Smoke Detector's battery (Fig. 39), it will greet users automatically: “(Ding-dong). Hi from Nest.” and begin helping users set the machine up by voice. Because of the timing and content of the guidance, the whole start-up process is explicit and efficient. Also, when the detector discovers a rise of carbon dioxide in home, it will

give users an early warning about the situation and the location. The color of the light also indicates the seriousness of the situation. Compared with traditional smoke detectors, Nest Smart Detector provides instant feedback, and users will even be able to know the exact location of the situation, which all help users to understand the product and the environment of their home.

Messages sent by the smart bathroom should also meet these requirements, providing users with the information of the content, location and details of the condition. With clear and sufficient information contained in the feedbacks, users can understand the condition easier.

**6. If it is hard to explain to users or requires text-heavy interpretation, illustrations or examples can be provided for clear explanation:**



**Fig. 40. Install Ring Doorbell with Phone**

Ring Doorbell is a smart doorbell that has a camera built in it, and can send messages to its users about what is happening at their front door. In order to install Ring, users need to set up the app and mount the doorbell into the wall. Because of the number of separated parts come with the



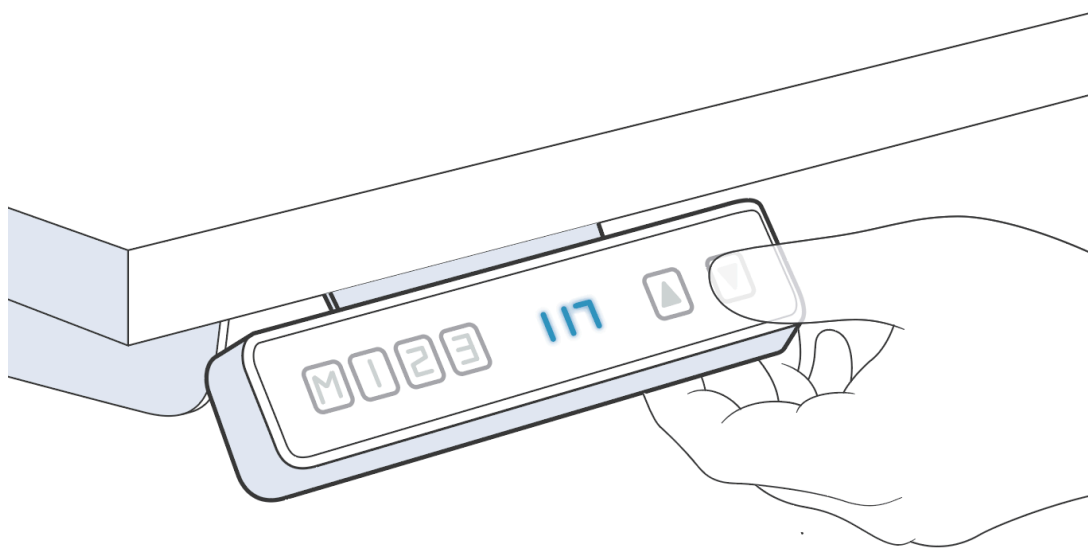
doorbell, and the complicated process of installation, the preparation process will be hard to operate for some users, and it is even difficult to explain to users. Hence, Ring Doorbell provides users with a short video to demonstrate the correct operation of preparation (Fig. 40), and the whole process is broken into multiple pieces so that users can follow the tutorial easily. Brief explanation is also provided to assist the video to make the preparation process more understandable.

When the installation of smart bathroom products is too hard to understand, designers can also use photos or pictures to explain the process, so that users will be able to follow the process easier.

#### 4.5 Flexibility

**The design should accommodate different users' diverse needs. The design should also meet each elder user's changing needs as he/she gets older. In different ways of achieving flexibility, users will have different levels of control of the design:**

**1. Adjustable. Users can adjust the design actively to fit their needs. An adjustable design can be considered when users need/want to have more control of the design:**

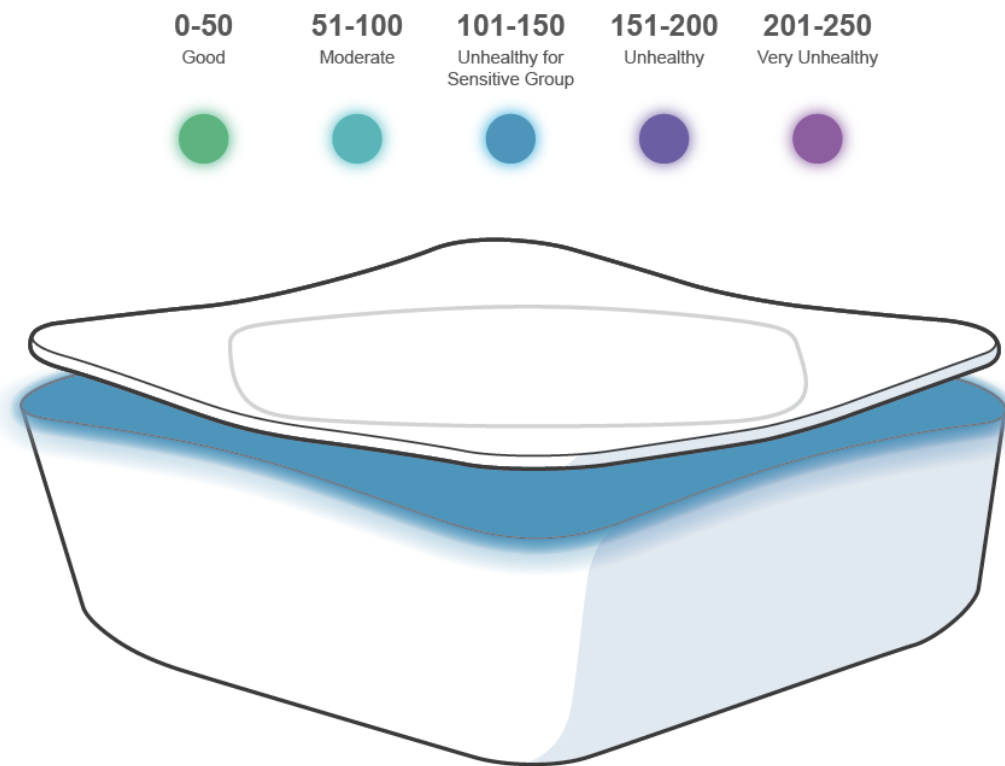


**Fig. 41. Zoria Table**

Fig. 41 is the corner of Zoria, a height adjustable table. Users can adjust the height of the table manually among three modes, and also adjust the table precisely by pressing the up and down button. The height of the table will be displayed on the screen. By adjusting the height of the table, users can either use the table while sitting or standing, which allow users to utilize the table with more flexibility.

The height of countertops or cabinets in the bathroom can also be adjustable so that users will be able to reach them when they are standing or sitting.

**2. Adaptable. The design itself can be aware of the context and adapt itself to the changes of the environment by switching among different presets:**



**Fig. 42. Acer Air Monitor**

By being adaptable, a smart home product can change actively according to the difference of the ambient conditions. For example, the Acer Air Monitor (Fig. 42) is a smart air monitor that

can automatically adapt to the quality of air detected by changing its light color, so that users will be able to understand the quality of the environment just with a glance.

Learning from the Acer Air Monitor example, the brightness in the smart bathroom can be adaptable to the light in the environment so that better room quality will be available for users with little effort.

**3. Responsive. The design can detect nuances of the environment and keep changing itself correspondingly in order to achieve maximum performance. A responsive design can be considered when small changes of the environment are vital and when users do not need to or cannot control the design:**



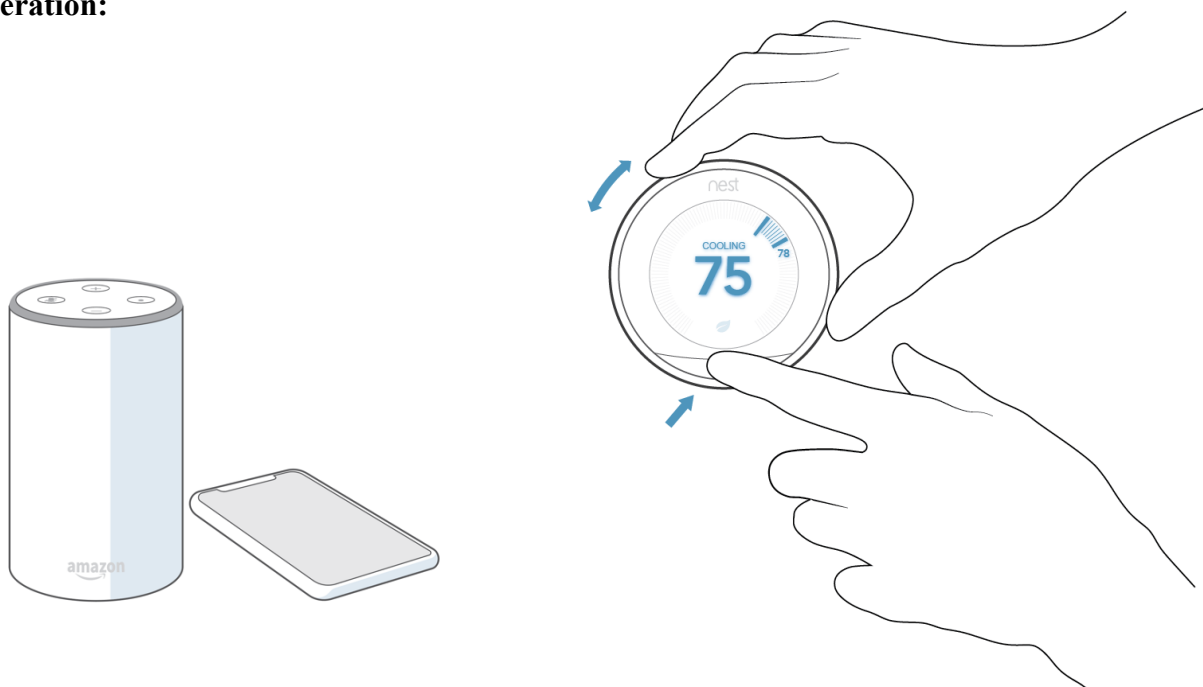
**Fig. 43. Xiao-Mi Eyecare Smart Lamp**

Xiao-Mi's Eyecare Smart Lamp is a lamp that is responsive to the level of light in the environment. The blue dot shown in Fig. 43 represents the light sensor which detects the ambient

brightness constantly. Once users choose the responsive mode, the lamp will adjust itself automatically to maintain the expected brightness so that readers do not need to adjust the lamp manually. By being responsive, users do not need to control the product, but the product will still function to achieve users' needs.

Inspired by the Smart Lamp example, the temperature of bathing water can be responsive to the ambient temperature, so that users will be able to enjoy the bath in a perfect temperature no matter of the season of the year.

**4. Allow different ways of achieving one task. Users' behavior can hardly be predicted, and they will be more likely to accept the design if they have more autonomy in operation:**



**Fig. 44. Different Ways of Operating Nest Thermostat**

Fig. 44 shows an example of multiple ways to operate Nest Thermostat. Firstly, there are two main gestures to operate Nest Thermostat face to face: twisting the rim and pressing the button. The combination of these two operations allow users to achieve simple and fundamental tasks such

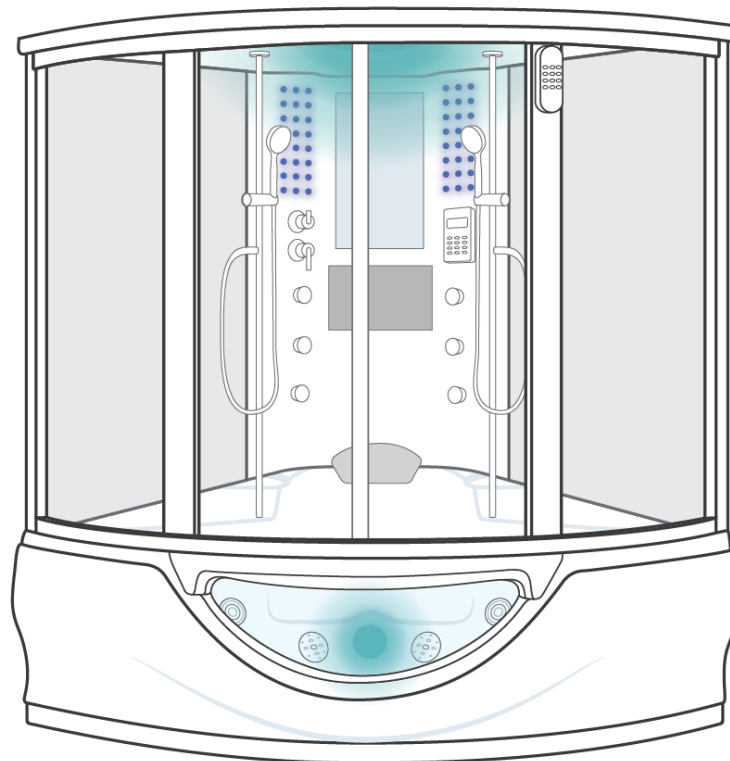
as choosing and confirming. Moreover, users can use a smart home hub, such as Echo, to operate the thermostat, and they can also accomplish more complicated tasks using the Nest Thermostat app. These various ways of operation give users full flexibility to use the product. They can use it by voice or gestures, and they can also use it at home or at a distance.

In the smart bathroom, in order to allow users to operate freely, for instance, designers can design the faucet to be operable via smart phones, smart home hubs or in person, so that users can adjust the faucet whenever and wherever they are.

#### 4.6 Simplicity

**Eliminate unnecessary functions and information. Reduce users' burden of using the design by keeping it simple:**

1. **Clarify the primary needs of the users and the ultimate goals of the design:**

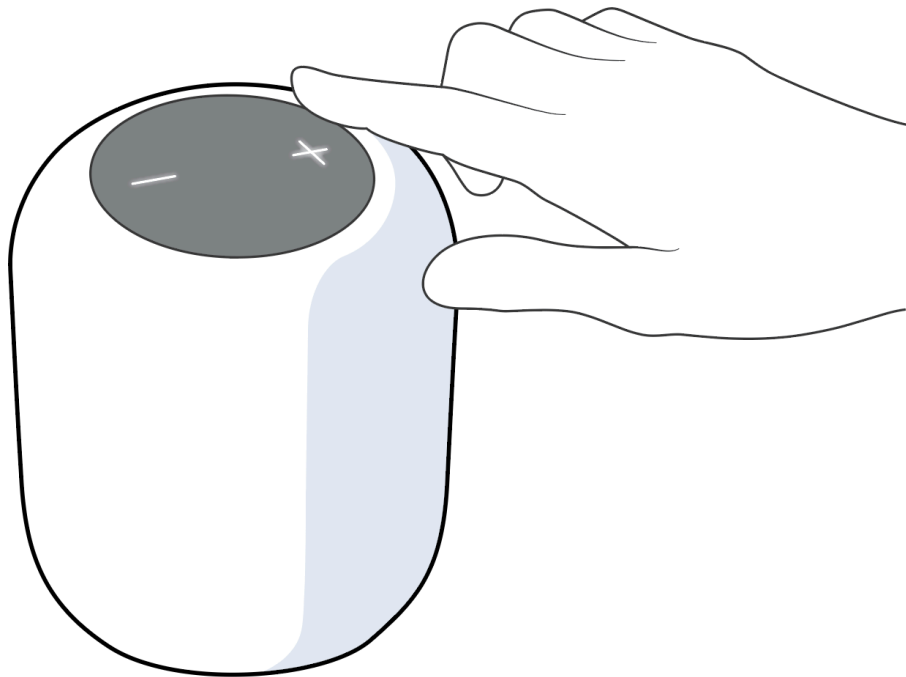


**Fig. 45. Shower and Bathtub by MayaBath**

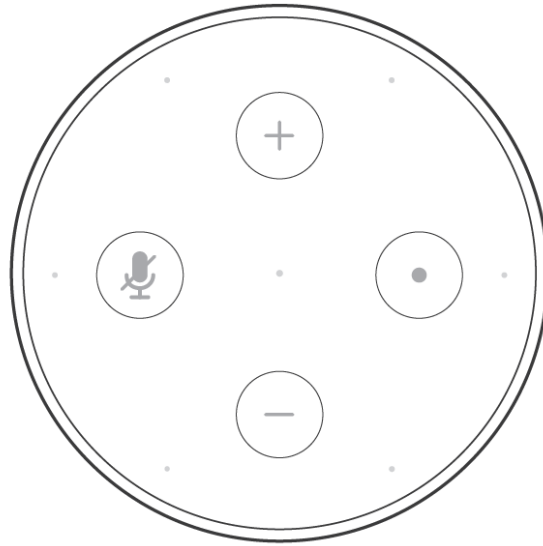
Fig. 45 is a luxurious shower and bathtub designed by MayaBath. This product combines a great number of fancy features, such as aromatherapy, music, LCD display, LED mood lights and foot massage, and is expected to entertain users and keep them in the bathroom for longer periods. However, this designer is far from the elderly users, whose main needs are mobility, self-care and finishing household activities, which cannot be seen in this concept.

Simplicity does not suggest designers to design the bathroom as simply as possible. Instead, simplicity means designers should clarify their targeted users and only keep features that will indeed be needed by them. Functions that look fancy but needless should be eliminated to maintain the simplicity of the design.

**2. Minimize the number of options by combining similar choices and limiting low-frequency choices.**



**Fig. 46. Apple HomePod**

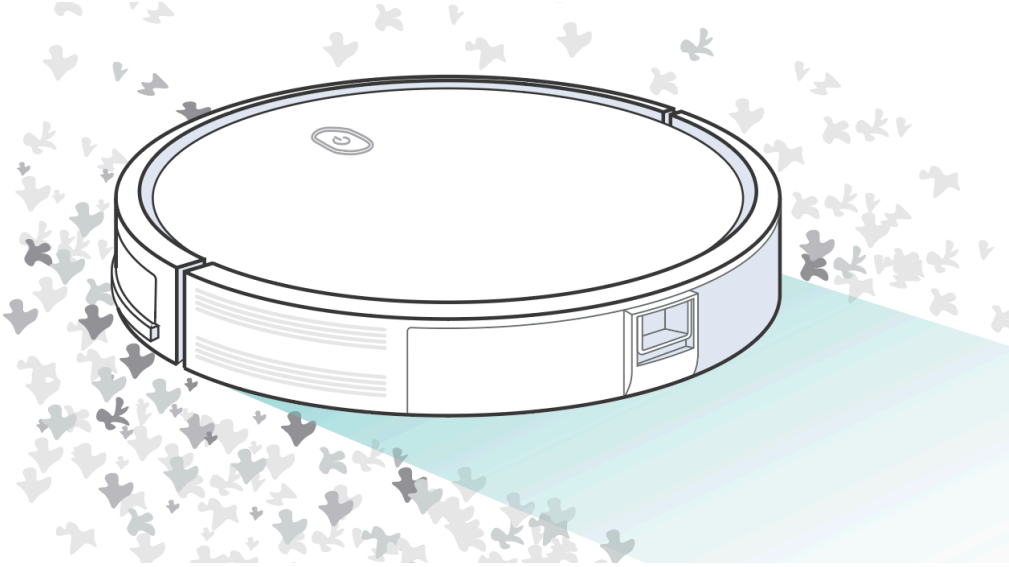


**Fig. 47. Top View of Amazon Echo**

The HomePod (Fig. 46) is a voice assistant made by Apple. When HomePod is sleeping, the top touchscreen is blank without any button, and button will only show up when they are needed. For instance, the two volume buttons will appear when user is playing music, and the function of buttons will change according to the task the HomePod is working on. By this activities-based display, HomePod does not need buttons most of the time, and only needed button will show up, which helps HomePod to maintain simplicity. Compared with HomePod, Amazon Echo (Fig. 47) is not as simple as HomePod, which has four physical and unchangeable buttons on the top.

Screens that will be used in the smart bathroom can learn from HomePod to achieve simplicity, which means buttons will be invisible when users have not made any commands, and will show up when they may needed.

**3. Fully utilize automation to reduce user’s physical and cognitive effort.**



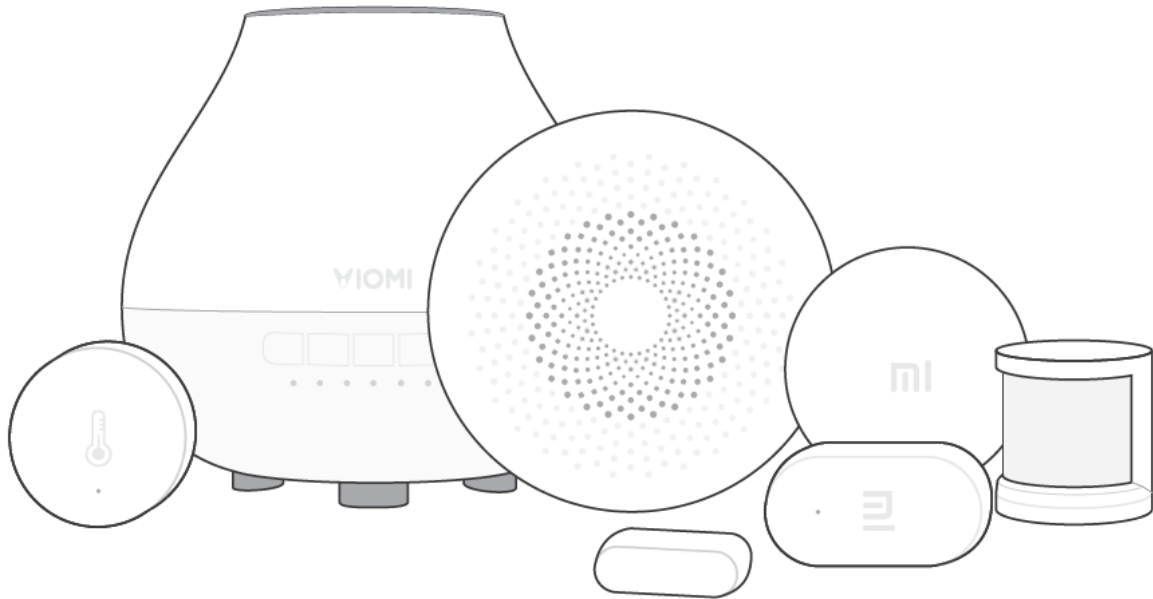
**Fig. 48. Robot Vacuum**

Robot vacuum (Fig. 48) is a perfect example of the benefits of automation. For robot vacuum users, in order to clean their home, the only thing they need to do is press the “start” button on the vacuum, and the robot vacuum will clean the home and move back to the charging location automatically when its work is finished. For elderly users, automation is so simple that it requires minimal operation from users. Hence, automatic products will reduce users’ physical and cognitive burden of operating the product.

For example, when the temperature in the bathroom can change automatically, there will no longer need to be any, or need to be few, air conditioning products, which will help the bathroom to maintain simplicity.



4. **Maintain visual simplicity such as using same elements, removing unnecessary decorations and maintaining structures.**



**Fig. 49. Xiao-Mi Smart Home Products**

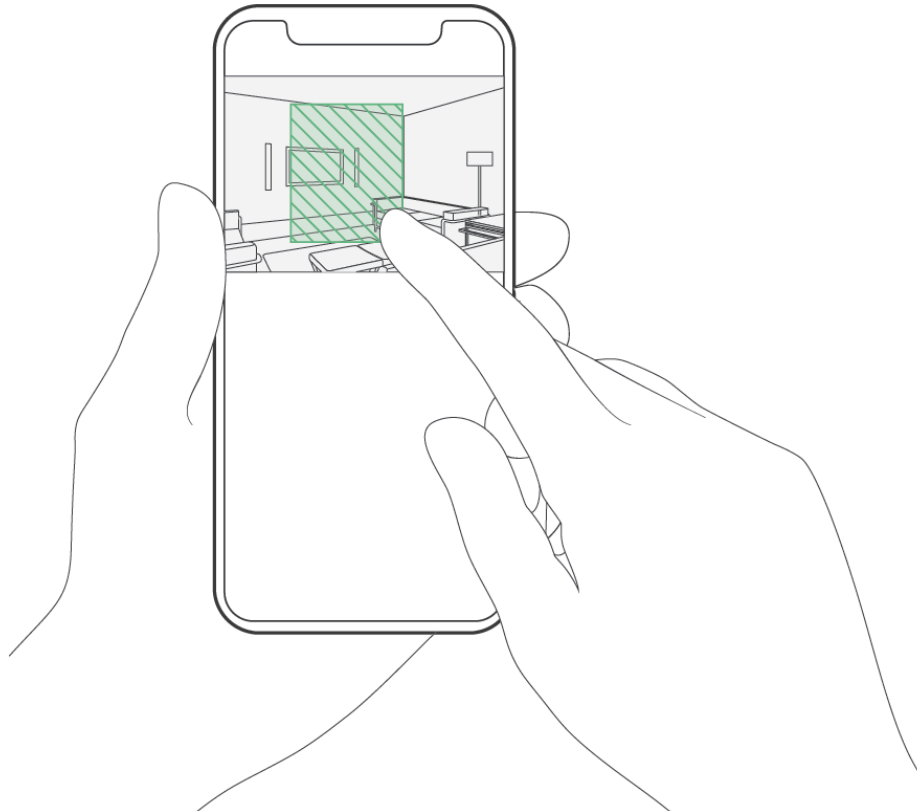
As introduced earlier, Xiao-Mi brand owns a great number of different smart home products (Fig. 49). Although Xiao-Mi plays a role in various product categories, those products obey the same visual principles, so that they still maintain simplicity even if there are many Xiao-Mi products in the home. For example, all Xiao-Mi products employ neutral colors, white, black and grey, which makes the design of Xiao-Mi products look clean. Also, Xiao-Mi products use minimal decoration, such as icon and logo. These features are carved or printed in light grey, which achieves a balance between complex and boring, and makes the design simple, but has details. Holes are also utilized to create textures of the products, which can not only add details to the design, but also keep decoration in order.

The decoration in the bathroom can also be simplified, eliminating unnecessary features, and bathroom appliances can be designed in a same way, such as using same colors and shapes, so that the bathroom environment will be clean and neat.

## 4.7 Reliability

The design should behave in a trustworthy way and minimize the likelihood of failing.

1. Respect the elderly person’s privacy, and ask for permission when the design is going to share or submit users’ information, which will help build the reliability of the products for users:



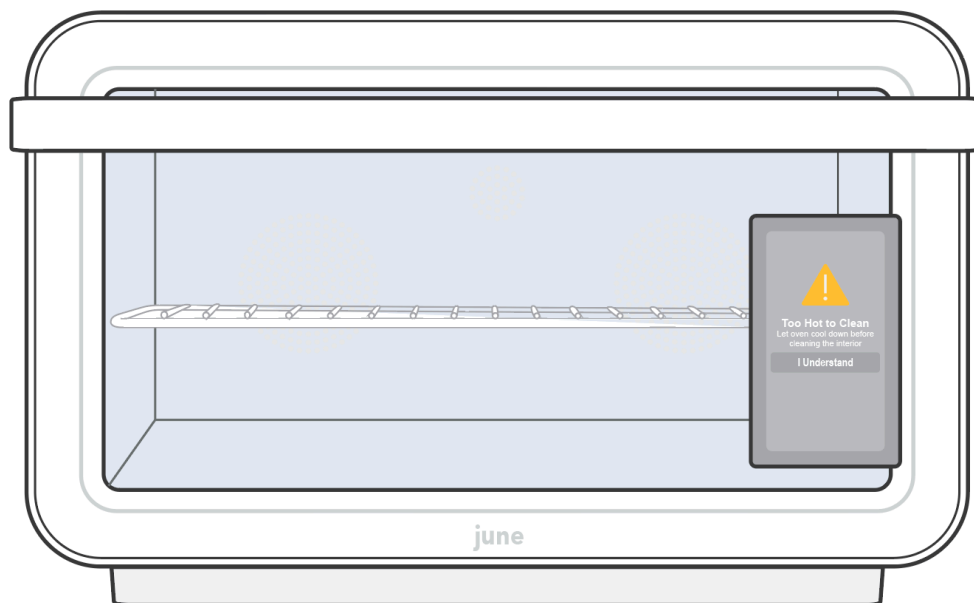
**Fig. 50. Amazon Cloud Cam**

Amazon Cloud Cam (Fig. 50) is a monitoring camera that can be used at home. The Cloud Cam can help home owners to detect who is at home and their movements, which will help users to protect indoor security and monitor the status of their family members. However, people who refuse to install a camera at home are most likely to be worried about their security, afraid of being recorded and leaked information. However, with Cloud Cam’s app, users will be able to DIY the zone that they want and do not want to be seen. By simply creating and dragging a “blind box” in

the app, the cam will not detect anything that is happening in the blind spots. This feature allows users to control their privacy precisely. Users will be able to decide what the machine can and cannot see, and therefore, will help designers to build reliability with users.

A smart bathroom may contain much sensitive information, such as users' habits of using the bathroom, and it is particularly important to let users know what information will be collected, and ask users for their permission when trying to use that information.

**2. Relieve the elderly person's fear of misusing the design by recommending correct usage, providing warnings of potential failings and allowing multiple tries:**



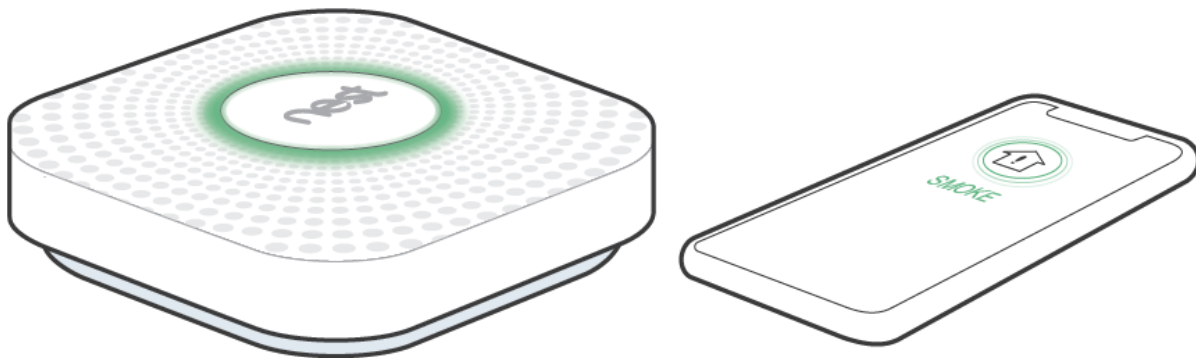
**Fig. 51. June Intelligent Oven**

June Intelligent Oven (Fig. 51) has a built-in screen and a small touch screen on the front of the oven. Many useful features are provided by June Intelligent Oven, such as programmed cooking and oven condition monitoring. June Intelligent Oven can also clean automatically. However, when users just finishing cooking and the oven is still in high temperature, the cleaning program will not be started. In this condition, if users ask the oven to clean, it will warn users clearly, explain to users the reason why the oven cannot clean itself, and tell users that they need

to wait till the oven is at a moderate temperature. In this case, although users have made a wrong command, they will not be afraid of misuse of the oven since the oven has given an explicit explanation and provided the right way to achieve their goal.

Similar design should be applied in the smart bathroom. When users attempt to use the design in a wrong way, such as trying to adjust the temperature to a value that is so high that will cause uncomfortableness, the design will notify users about what will happen and the consequences, and how to use the design. By doing so, users do not need to be afraid of misusing the design, and can be guided correctly.

**3. Be prepared for failures. Provide solutions for functioning in failing scenarios and recovering:**



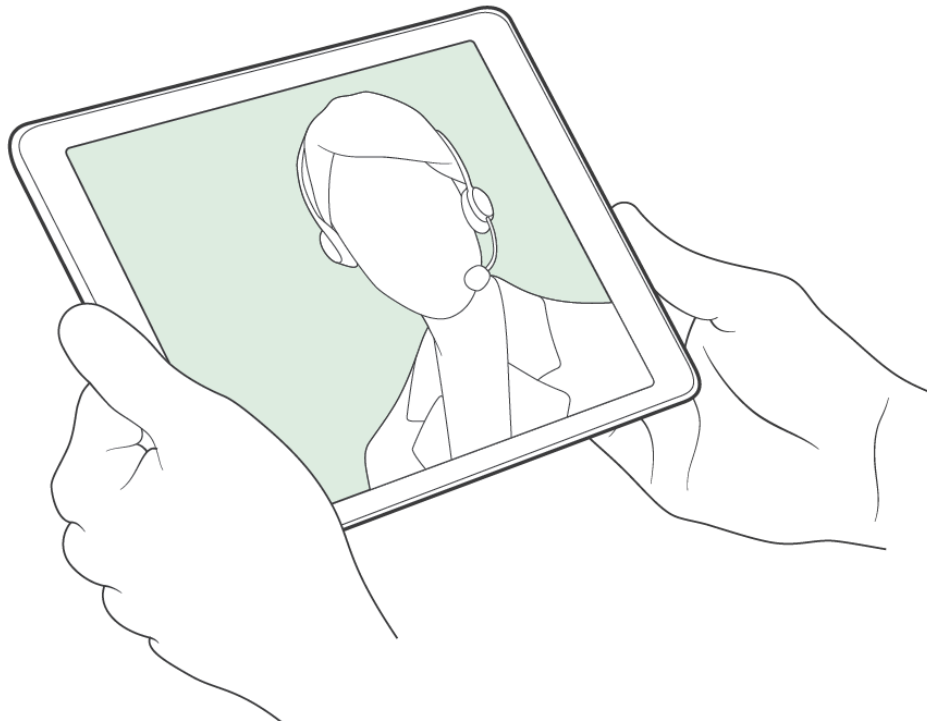
**Fig. 52. Nest Smoke Detector**

When there is fire at home, Nest Smoke Detector will alarm with buzzing and voice, and send message to users' phone (Fig. 52), so that users can rush to home to solve the danger. However, what will happen if there is a power outage and Nest is out of electricity? First of all, if Nest lost a connection to electricity during a power outage, it will send a message to user's phone and suggesting them to charge it in time. Also, Nest Smoke Detector has three backup batteries, which are designed for long-lasting life and will not be used until there is an emergency such as a power outage. By ensuring the maximum performance in failing scenarios, design will be more

reliable, and users can acquire assistance from and rely on these designs to help them go through difficult times.

The smart bathroom should also consider conditions such as power outages, and sufficient electrical power should be stored to assure that the design can go through these situations.

**4. Integrate the advantages of cooperating with stakeholders (caregivers, relatives...) when it is necessary:**



**Fig. 53. Philips CareSensus Project**

Philips CareSensus (Fig. 53) is a healthcare project that monitors the activities of users and provides them with real person assistance when it is needed. Users participating in the program will receive activity trackers that will be installed all over the home, such as on the front door, on the refrigerator's door and in the living room, with which users' activities will be comprehensively documented and analyzed. If an exception from the normal routine is detected, such as the user has been in bathroom for an hour, a home care agency will provide intervention instantly, such as

making a remote call. Sometimes, simple monitoring and analyses of users' behavior are not sufficient enough to provide practical help to users. With the intervention of real person, the value of these data will be given full play to, and the reliability between users and design will be strengthened.

Smart bathroom design can learn from the CareSensus example, integrating the help of real people such as relatives and care providers when unusual conditions happen, such as users have fallen on the ground and cannot stand up on their own.

## **Chapter 5**

### **Conclusion**

#### **5.1 Conclusion**

The population is aging rapidly worldwide. Life expectancy of the elderly population is rising significantly. It is clear that the living condition of elderly people will be a serious problem at present and in the future. At the same time, many of them prefer to age in place as long as possible, which makes the home environment an important feature of the wellness of the elderly. However, with physical, sensory and cognitive limitations, they have a lot of problems in mobility, self-care and household tasks at home. Activities in bathrooms, such as toileting, bathing and showering, are particularly troublesome for elderly people. Considering the benefits of smart home technology, this study believes that a smart home will be a solution for aging in place independently. In order to instruct designers to design a bathroom that can help elderly people finish bathroom activities independently, an approach and design guidelines of smart bathroom design for elderly population is proposed in this study, which mainly includes the following aspects:

Firstly, in order to maximize the effectiveness of the approach, designer should finish the preparation process, which includes problem discovery, problem identification, research and problem statement. After these steps, designers are expected to develop an in-depth understanding of the issue that they are studying.

The second part of the approach is the ideation process. During ideation, designers will need to place the bathroom space first, and then they will design the services, physical products and interfaces of the bathroom. The content of these four design aspects are comprehensively listed, and designers should follow the six principles to accomplish them. For each of the principles, several guidelines are provided to assist designer to put the design into practice.

The last part of this study is the demonstration of the six design principles and their corresponding guidelines. In this section, each design guideline is clearly introduced with an illustration from the smart home market, so that readers and designer should be able to understand the guideline and be able to apply them.

## **5.2 Suggestions for Future Application and Development**

This study will only be applicable to smart home products. Users can utilize the problem identification tool to check the applicability of their design problems. Tools of each design process are provided, and the use of each tool is comprehensively explained, so that designer should be able to apply the design into practice instantly.

Although the guideline is specifically proposed for senior population and bathroom design, the author of this study believes that this guideline will also be valuable when designing for people with limited abilities, and when designing other products in a smart home.

The anticipated result of the application of this guideline will be a smart bathroom that is assistive for the elderly. The scope of this study does not include evaluation, and it is suggested that designers should go through the evaluation process before releasing their design into the market.



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## **Appendix 1 – Interview Questions of the Elderly’s Level of ADLs and IADLs**

I’m Huanyun Wang, from the School of Industrial and Graphic Design at Auburn University. I’m working on a project which is aimed at helping the elderly stay and live comfortably and independently at home as long as possible. I would like to know how you are helping the elderly and what challenges they will have when they are living at home.

These questions will take about 10-mins, and I will record our conversation if you don’t mind. It will not be published or shared but will help me in initiating my research and design project.

1. What are the 3-5 most common reasons that elderly need your home health services?
2. How frequently does a home health care professional visit a patient? (several times per day, daily, weekly, monthly?)
3. How long does a home health care professional typically stay with a patient during their home visit?
4. Aside from any medical treatments or therapies administered, are there any other tasks around the home in which they help patients? If so, what?
5. Do patients ever ask for help with other household tasks? If so, what?
6. What was the most unusual task you’ve been asked to help a patient with?
7. Is there a particular area or task that you’ve seen to be the most problematic?
8. If you were designing the ideal home for elderly with limited abilities, which room would you suggest I begin and why?
9. How would the ideal home work for someone who struggles with limited abilities?

## Appendix 2 - Materials for The Study of Elder's Difficulties in Their Bathroom

Title	Authors	Year
Bathing Disability in Community-Living Older Persons: Common, Consequential, and Complex	Aanand D. Naik John Concato Thomas M. Gill	2004
Bathroom Modifications for Frail Elderly Renters: Outcomes of A Community-Based Program	Laura N. Gitlin Kathleen Swenson Miller Alice Boyce	1999
Gerotechnology Series: Toileting Aids	D. Harman S. Craigie	2011
The Preference and Importance of Bathing, Toileting and Mouth Care Habits in Older Persons	Jiska Cohen-Mansfield Barbara Jensen	2005
Elderly People at Home: Technological Help in Everyday Activities	M. V. Giuliani M. Scopelliti F. Fornara	2005
The Use of Technical Aids Among Community-Based Elderly	Mark G. Parker Mats Thorslund	1991
Managing Activity Difficulties at Home: A Survey of Medicare Beneficiaries	Brian J. Dudgeon Jeanne M. Hoffman Marcia A. Ciol Anne Shumway-Cook Kathryn M. Yorkston Leighton Chan	2008

Thermal Conditions in the Bathroom in Winter and Summer, and Physiological Responses of the Elderly during Bathing	Kiyoko Kanda Jun Tsuchiya Masako Seto Tadakatsu Ohnaka Yutaka Tochihara	1995
Aging in Place Bathrooms	/	/
Falls and Fall Prevention in the Elderly: Insights from Jamaica	Kenneth James Jacqueline Gouldbourne Chloe Morris Denise Eldemire-Shearer	/
Perspectives of Older Persons on Bathing and Bathing Disability: A Qualitative Study	Sangeeta C. Ahluwalia Thomas M. Gill Dorothy I. Baker Terri R. Fried	2010
Factors Associated with Toileting Disability in Older Adults without Dementia Living in Residential Care Facilities	Kristine M.C. Talley Jean F. Wyman Ulf G. Bronas Becky J. Olson-Kellogg Teresa C. McCarthy Hong Zhao	2014
A Friendly Rest Room: Developing Toilets of The Future for Disabled and Elderly People	Dries Dekker Sonja N. Buzink Johan F.M. Molenbroek	2011

	Renate de Bruin	
Bathing for Older People With Disabilities	Abir Mullick	1993