A Procedure Model for Developing Gerontechnological Solutions to Achieve Demographic Sustainability in Aging Society

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1 Introduction

Population aging is arguably one of the greatest challenges facing human society today. In addition to being a serious challenge in wealthy nations, it poses a rigorous threat to emerging economies. As of today, there are more than 8 billion individuals living on this planet, of which 9.6% (771 million) are over 65 years old. Globally, the population aged 65 years or over is the fastest-growing age group, whose proportion increased from 6.9% in 2000 to 10% in 2022 and is projected to reach 16% by 2050 (United Nations 2022).

The World Health Organization (WHO) refers societies where older population aged 65 years and over takes up 7%, 14%, and 21% of the total population as "aging society," "aged society," and "super-aged society," respectively. The general trend is that the higher the income of a country, the more serious the aging problem. Specifically, the situation of population aging varies drastically in different countries. As a result, the challenge of population aging is especially prominent in the most developed countries. In Germany, for example, the current percentage of

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population aged 65 and over has exceeded 21.7% (i.e., 18.2 million), which already met the standard of "super-aged society." Japan is another prominent example of "super-aged society" that faces an even more serious aging situation than Germany. Due to a high life expectancy and a low fertility rate, the percentage of the Japanese population aged 65 and over reached 28.4% in 2020 and will continue to increase to 37.7% in 2050 (United Nations 2019). As the population's income increases, population aging also becomes a rigorous challenge in emerging economies such as China and Africa. In China, the population is currently experiencing a rapid, accelerated aging process due to several reasons such as improved medical standards, economic pressures, and decades-long family planning policies. By the end of 2020, Chinese older adults aged 65 or over reached 191 million, accounting for 13.5% of the total population, which was nearly equal to the total population of Germany and Japan combined (National Bureau of Statistics 2021). Moreover, it is anticipated to spend the shortest period (i.e., 33 years) to transfer from "aging society" to "super-aged society" compared to any major developed countries in the world, which gives it much less preparation time to brace for social impacts caused by population aging (Chen et al. 2019). Even in Africa, although the median age of the continent's population is only 19.7 years as of 2020, the number is projected to be 34.9 by 2100. Accordingly, Africa's percentage of population aged 65 years or over will increase to 13.9% by 2100 (United Nations 2019), which will essentially meet the definition of aged society as well.

Population aging has many consequences for society, such as increased chance of getting chronic noncommunicable diseases among older adults, growing healthcare expenditures especially on long-term care (de Meijer et al. 2013), labor shortages, and slowing economic growth (Bloom et al. 2011). Therefore, novel approaches are needed to address these consequences. This chapter mainly focuses on proposing a methodological framework as well as technological solution to address the population aging phenomenon and its consequences, eventually contributing to demographic sustainability.

2 Methods

There are many types of methods for continuous product improvement which is also known as "kaizen," meaning change for the better in Japanese (Imai 1986), such as Kanban (Powell 2018), Six Sigma (Antony 2006), Look-Ask-Model-Discuss-Act (LAMDA) (Tortorella et al. 2015), and Plan-Do-Check-Act (PDCA), among which the PDCA method is arguably one of the most known and applied one worldwide (Realyvásquez-Vargas et al. 2018).

The PDCA Cycle (also referred to as the Deming Cycle) is an iterative process management model for the continuous development and improvement of products, which is widely popular for its originality, simplicity, and practicality. It was first introduced to the Japanese by W. E. Deming in the 1950s in order to improve product quality and satisfy customers, which was further developed by the Japanese into a systematic tool for continuous product development called the PDCA model (Imai 1986), which was also adopted by the Western industry in the 1980s (Nilsson-Witell et al. 2005). The model consists of four phases: Plan, Do, Check, and Act. The phases are worded slightly differently in different literature but have the same purpose which is to continuously improve (Lodgaard et al. 2013). Generally speaking, the Plan phase includes identifying and analyzing the problem; the Do phase includes the development and implementation of the solution; the Check phase includes the evaluation of the result to check whether the goal is achieved; and the Act phase includes activities such as standardization and knowledge transfer (Johnson 2002).

The PDCA model was also adopted in the development process of automated building technology systems. For example, mainly based on the consultancy project investigating the potential of implementing robotics and automation in the context of large-scale housing development for Hong Kong as well as several other research projects on developing construction robots, Linner et al. proposed a PDCA-based technology management system for the development of single-task construction robots (STCRs) based on the analysis of several exemplary research and development (R&D) projects in that field (Linner et al. 2022). The Ambient Rehabilitation Kit reported in this chapter can also be considered a special type of robotic system due to their common purpose of supplementing human labor with automation technology. Therefore, it is reasonable to apply this methodology in the development process of ambient health-promoting system as well.

As shown in Fig. 1, the basic structure of this methodology is based on the PDCA model. Flexible starting point and continuous improvement are important for developing gerontechnology products because it is difficult to immediately specify the requirements, system architecture, work process, and business strategy. Therefore, an iterative and cyclic approach is appropriate. The primary goal of the proposed procedure model is the continuous evolution of the system architecture and the technical readiness levels (TRLs) of its subsystems (Layer 1). The core elements around the center are the four primary development phases based on the V-Model, which are requirements engineering, development, performance evaluation, and implementation (Layer 2). Guided by the Deming Cycle (Layer 3), each phase consists of various modular steps belonging to this phase such as specific activities and tasks (Layer 4). The non-inclusive activities and tasks listed in Layer 4 essentially constitute a modular toolkit to complete the system development goal in several iterations, some of which can be repeated in different cycles to fit different contexts and regions.

3 Results

The results of this chapter are based on the case study of a large European research project entitled REACH (Bock 2017), which implemented this procedure model in its development cycle.

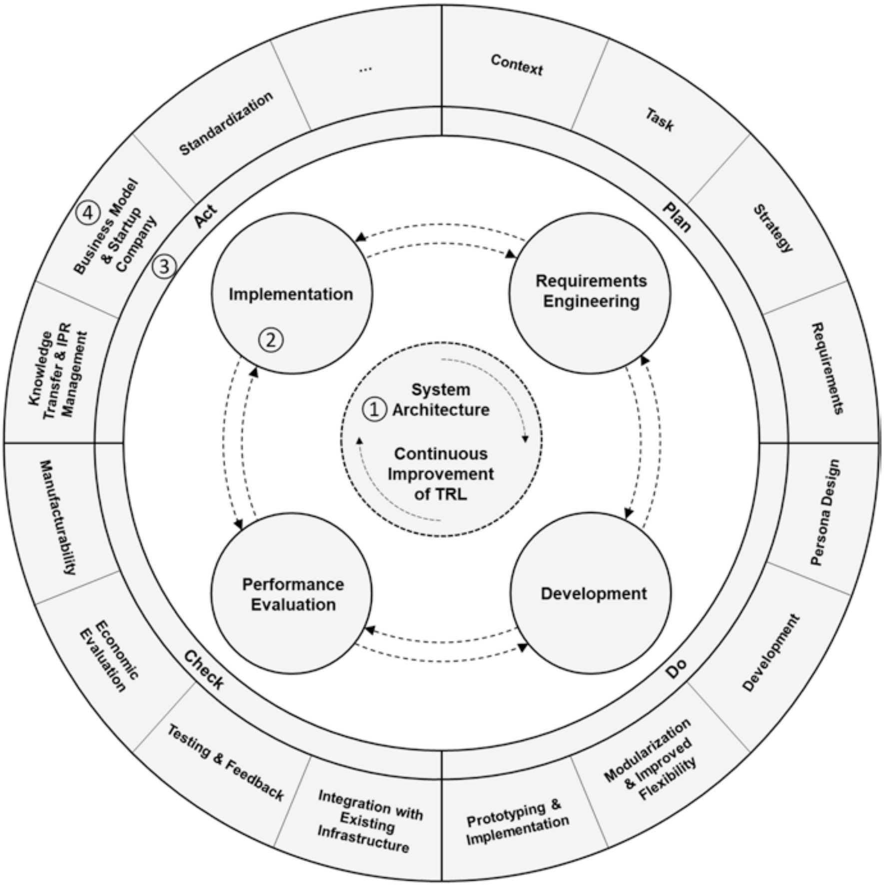

Fig. 1 The procedure model for developing gerontechnology systems. (Adapted from Linner et al. 2019)

3.1 State-of-the-Art Analysis and Shortcomings (Plan)

The original ideas of assistive home environment for aging society can date back to the 1980s where co-author T. Bock developed the life support system (LSS) for older adults, which was sponsored by the Japan Science Society. The concept depicted visionary functions such as assisted dressing, smart home control, automated body turnover, telemedicine, and emergency evacuation (see Fig. 2).

In recent years, due to the pressure from social challenges such as aging societies, limited resources, and a continuously increasing demand for productivity and efficiency, the topics of assistive smart furniture and smart homes have attracted more attention.

It has been demonstrated that smart furniture to a limited extent can integrate sensory and intervention functionality into the living environment. Notable

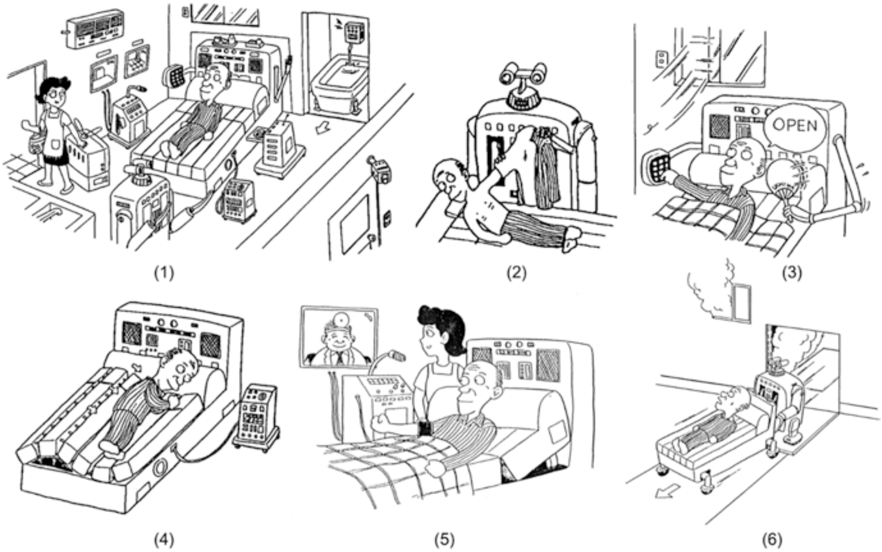

Fig. 2 The first concept of life support systems for aging society in Japan. (Image: T. Bock)

examples are smart chair (Erdt et al. 2012), smart bathroom (Manoel et al. 2017), smart kitchen (Beetz et al. 2008), and smart bed (Spillman et al. 2004). An obvious shortcoming of these furniture schemes is that the majority are stand-alone devices that are not integrated into a larger system or are incapable of monitoring the entire area where they are positioned. An additional weakness is the lack of modularity and the limited amount of functionality the systems provide. In the meantime, researchers have also proposed several intelligent sensing solutions, including the Aware Home (Kidd et al. 1999) and the RoboticRoom (Sato et al. 2004), both of which are ambitious concepts of smart environments using intelligent robots and sensor networks. However, they lack the capacity to be integrated into a regular home or care environment due to the high cost, the high complexity, and the need for fundamental changes to the existing living environment. Recently, researchers have been focused on transforming the built environment into smart assistive environment for older adults. However, many of these attempts employed intrusive sensory and motivation functions into the built environment to support the monitoring and care to improve older adults' health and independence (Sakamura 1996; Intille 2002; Sato et al. 2004; Pyo et al. 2014).

In order to address the shortcomings of the state-of-the-art gerontechnological systems, a series of research projects, including but not limited to GEWOS (Linner and Schulz 2015), PASSAge (Bock et al. 2015), USA[2] (Linner et al. 2016), LISA Habitec (Güttler et al. 2017), and BaltSe@nior (Langosch et al. 2019), were carried out by the Chair of Building Realization and Robotics at the Technical University of Munich (TUM), tackling various aspects of gerontechnology such as exercise, mobility, working, activities of daily living (ADLs), and fall detection respectively. However, there are various shortcomings still existing in the state-of-the-art assistive technology as well as latest research projects, including a lack of modularity, compatibility, flexibility, rehabilitation functionality, fall prevention, financial feasibility, and scalability outside Europe. Therefore, a comprehensive solution that goes beyond the state of the art is demanded.

3.2 Touchpoints and Engine Concept (Plan)

The research team proposed the Touchpoints and Engine concept as the comprehensive system architecture for the project. Based on this concept, the product-service-system architecture of REACH is divided into six manageable research and development clusters: four "Touchpoint" clusters that represent tangible connections between the REACH system and users such as older adults and caregivers; one "Engine" cluster, which is a cloud-based digital platform serving as the brain of the project; and one "Interface" cluster, which comprises a set of means that allow the Touchpoints and other products and services to interact with the Engine (see Fig. 3). Each cluster is associated with a dedicated and independent development team coming from the project consortium members. The work presented in this chapter is mainly related to Touchpoint 2 – Active Environment.

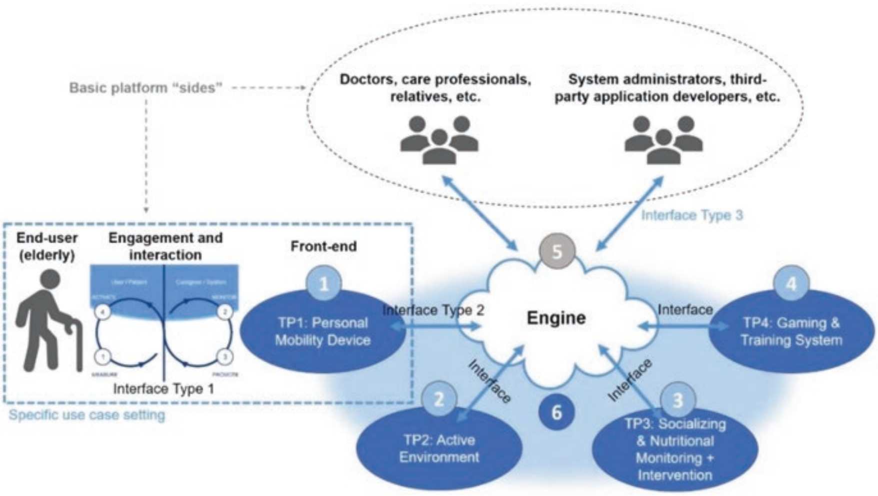

Fig. 3 "Touchpoints and Engine" concept in the REACH project

3.3 Determining Users' Requirements (Plan)

In order to achieve a successful development process, it is necessary to conduct requirements analysis before the design process starts. A description of the target user including the user environment and an analysis of the entities associated with the user were performed. Various methods were applied to describe and analyze these key components of the REACH system, including describing use cases, defining personas, creating experience maps, and analyzing stakeholders (Schäpers et al. 2017). Subsequently, the major hypotheses of four Touchpoints were concluded based on these analyses. For example, the hypothesis of Touchpoint 2 is formulated as follows: the REACH system based on smart furniture elements with sensing systems enables the patients to reduce the duration of their hospitalization, reduce decline after discharge, reduce risk of readmission, and be able to perform their ADLs with reduced support from professional caregivers.

Based on the result of the requirements engineering, the extracted raw requirements were further formalized and assigned to specific requirements categories (e.g., health outcome requirement, regulatory requirement, stakeholder requirement, etc.). All outcomes of the activities in the requirements engineering (e.g., stakeholder analysis, co-creation workshop, analysis of best practice, business strategy, motivation analysis, data management, ethics study, intellectual property management, etc.) were systematically summarized, and the key points were extracted and translated into raw requirements.

3.4 Ambient Rehabilitation Kit: An Unobtrusive Interdisciplinary Approach to Achieve Demographic Sustainability (Do)

The relevant requirements of the system can be materialized by a series of Personalized Intelligent Interior Units (PI^2Us). The PI^2U is a special type of smart furniture that seamlessly integrates the required concepts and functionality into the different use case settings. This chapter focuses on a series of PI^2Us developed by the project team in Touchpoint 2 (i.e., the "Active Environment" work group of the project). The relevant PI^2Us include SilverArc, MiniArc, SilverBed, iStander, and ActivLife. The term "Silver" implies the color of older adults' hair, which is in line with the booming silver economy.

The SilverArc is a multifunctional device developed for the use in a large kitchen or dining space (e.g., a community kitchen). The dimensions can be easily adapted due to the telescopic design. It offers an interactive projection area in the kitchen, where recipes and training programs can be displayed. It also has a foldaway projection area where an elderly-friendly graphical user interface (GUI) can be displayed. The MiniArc can be considered as a flexible and smaller variant of the SilverArc, which is meant to assist in the training and moving of older adults who are

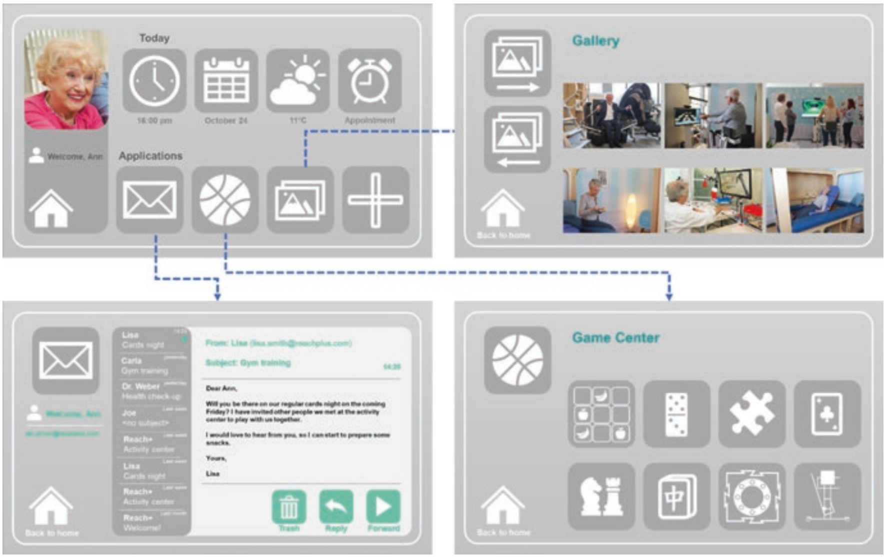

Fig. 4 Design of the GUI's home screen and second screens

hospitalized or reside in smaller apartments. This prototype was fitted with wheels and is thus mobile. The philosophy of inclusive design was also considered so that a user in wheelchair can easily push the wheelchair in between the wheels (i.e., 895 mm). An ultrashort projector can project the GUI on its foldaway table or on a separate table as needed. Meanwhile, a motion-sensing camera (i.e., Microsoft Kinect) is integrated to detect the user's gestures, enabling the interactive gesture control and gaming function. The major features of the GUI for both SilverArc and MiniArc include calendar, weather, appointment reminder, email, game center, and photo gallery (see Fig. 4). In addition, an infrared camera can detect user's respiratory rate using machine learning.

SilverBed is a carpentry-based modular bed incorporating Sara Combilizer that assists older adults to move autonomously to a sitting, standing, or supine position in a comfortable and safe manner. Physical exercise is offered in combination with entertainment, motivating its users to become more active. More importantly, health functions can be also integrated such as vital signs and skin pressure monitoring.

ActivLife is equipped with a mechanism to assist the user to stand up and to perform motor exercises of the ankles, knees, and hip joints. It also allows the user to maintain a safe, upright standing position and perform physical-mental serious gaming and balance exercises through the motion-sensing TV component.

Furthermore, based on the PI^{2}Us, a modularized smart home solution, namely, Ambient Rehabilitation Kit, was proposed, integrating the smart furniture and key technologies in REACH to create a complete interior living and care environment (also known as the smart infill system in open building) for older adults in different

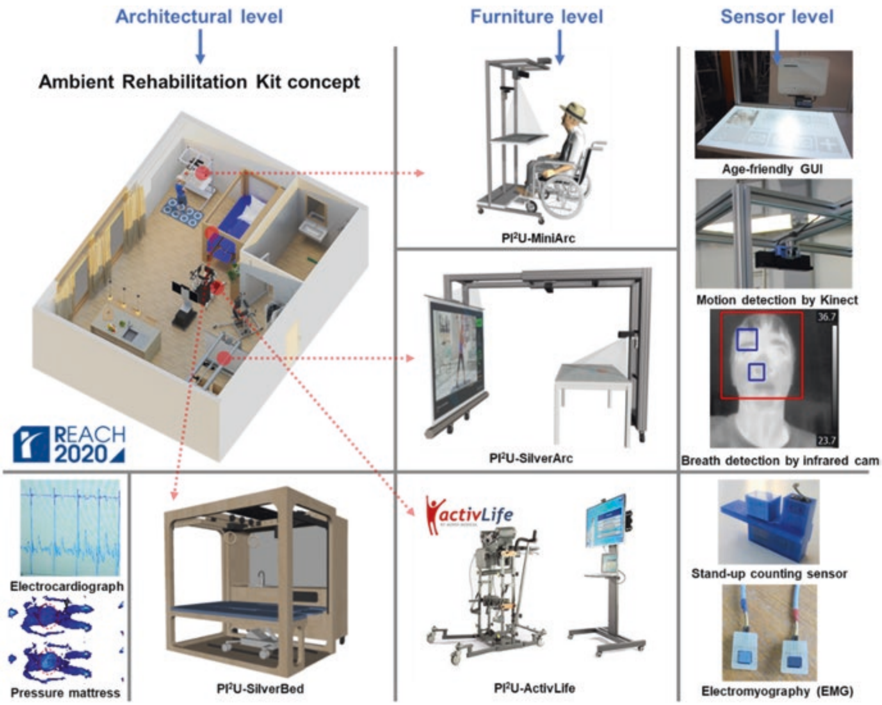

Fig. 5 Ambient Rehabilitation Kit concept

living environments such as home, hospital, and community in a flexible and adaptable manner (see Fig. 5).

Thereafter, all the data collected via a variety of sensors integrated into the PI²Us (e.g., electrocardiography, thermal camera for breath detection, body pressure mapping system, stand-up counter, etc.) will be transferred, exchanged, and stored securely via the CARP platform, which is a set of open-source software components and frameworks developed by project partner Technical University of Denmark (DTU). The platform enables the design and development of mobile health applications for digital phenotyping research (https://carp.cachet.dk/). The PI²Us, the distributed intelligent home concept, and the CARP platform were tested and validated in several exhibitions and tests across Europe later on (Hu et al. 2020).

3.5 *Strategy for Testing and Exhibition (Check)*

After the development of the various PI²U prototypes, a series of testing and exhibition activities were carried out to verify the functionality, operability, and usability of the PI²Us. These activities followed a "lab-field-showroom" approach that is also an important component of the Ambient Rehabilitation Kit where the lab

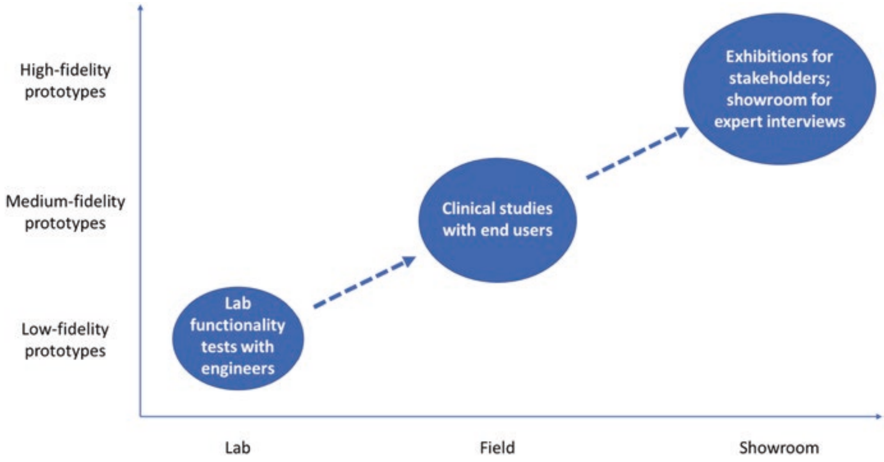

Fig. 6 "Lab-field-showroom" strategy for testing and exhibitions

decontextualized (i.e., with low-fidelity prototypes and environment), the field contextualized (i.e., with medium-fidelity prototypes and environment), and the showroom enabled users to experience the tangible technologies (i.e., with high-fidelity prototypes and environment) (Koskinen et al. 2013) (see Fig. 6).

3.5.1 Main Sensing, Monitoring, and Analysis Functionality Testing by Engineers ("Lab")

As mentioned in the previous sections, a series of PI^{2}Us are developed in Touchpoint 2. The PI^{2}U prototypes are manufactured, deployed, and tested for main sensing, monitoring, and analysis activities in the laboratory (see Fig. 7). The qualitative functionality testing of these activities is presented as follows, which clearly demonstrates how various sensors and functions can be integrated into the PI^{2}Us due to their modularity and customizability.

3.5.2 Clinical Studies Using PI^{2}Us in Touchpoint 2 ("Field")

After the prototypes of PI^{2}Us were built, the evaluation was conducted in various care facilities with partners. In the REACH project, more than 30 testing activities including tests, studies, and clinical trials were conducted. All trials in the project were in conformity with ethical principles set by the Declaration of Helsinki. Data were collected and processed following the legal requirements for data protection. The testing activities demonstrated that the PI^{2}Us are safe and useful for the rehabilitation and independence of older adults (Steinböck et al. 2019; Lu et al. 2020; Randriambelonoro et al. 2020).

Fig. 7 The prototypes of various PI²Us deployed and tested in the laboratory

3.5.3 Exhibitions and Expert Interviews ("Showroom")

During the REACH project, the developed smart furniture was exhibited in several exhibitions and trade fairs (see Fig. 8), which is an important and effective approach to disseminate the products due to its personal communication nature (Kellezi 2014). In addition, an expert interview was conducted in the simulated home environment at TUM, which is another effective qualitative research method to improve the future iteration of the abovementioned PI²U prototypes (Döringer 2021). As a result, all five experts from the related fields (e.g., engineering, fashion, healthcare, business, education) all had highly favorable opinion towards the prototypes in the showroom, which established a strong endorsement to the Ambient Rehabilitation Kit (see Fig. 9). In addition, the experts suggested the following improvements to be considered in the next round of iteration:

(1) The volume and weight of the prototypes shall be further reduced to better fit the home environment.
(2) Classic functions that are familiar to older adults such as a radio module as well as information about its programs shall be integrated into the GUI of the MiniArc and SilverArc.
(3) The algorithm of the GUI of MiniArc and SilverArc needs to be further optimized to enhance the user experience of gesture maneuver.
(4) The ergonomics of iStander and SilverBed can be further improved.
(5) The costs of the PI²Us shall be considered and optimized to improve affordability.

Fig. 8 Aerial view of the REACH exhibition venue that more than 200 people attended

Fig. 9 Testing process with the experts in simulated home environment ("showroom") at TUM

3.6 A Framework for Economic Evaluation of Robotic and Automated Systems (Check)

No matter how advanced and efficient an innovation is, if it cannot achieve profitability, it will not be successful due to the lack of investment motivation. Therefore, this section aims at proposing a simple framework for the economic evaluation of robotic and automated systems for the healthcare industry. It is widely known that cost-benefit analysis (CBA) is considered to be the most important problem-solving tools in the decision-making process (Munger 2000), yet there is a lack of research on the CBA of smart home solutions for aging society. Therefore, based on the methods proposed in this chapter, the following section focuses on using the simple framework to evaluate economically smart furniture solutions compared to traditional care methods in various care environments.

The CBA followed the analytical framework described in Fig. 10 (Hu et al. 2021). In the calculation process of the CBA, all relevant factors that affect the main stakeholder need to be considered. Normally, the cash flow analyses for CBA range from at least three (small-scale projects) to more than ten years (e.g., large-scale public projects) (Li and Madanu 2009; Jones et al. 2014; Wang et al. 2014). Due to the public welfare attribute of the Ambient Rehabilitation Kit, it is appropriate to set

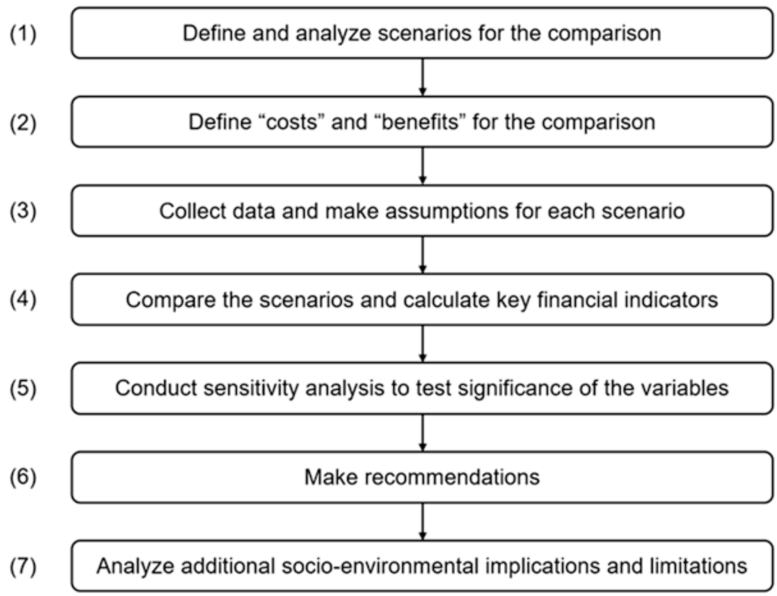

Fig. 10 The analytical framework of cost-benefit analysis (CBA) applied in this research

AAL Service Financial Evaluation									
Cash outflows	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Total (€)	Remarks
Central - hardware costs								0	
Central - software costs								0	
Central – network costs								0	
Service implementation								0	
Per patient costs - hardware								0	
Per patient costs - software								0	
Per patient costs - network								0	
Per patient costs - install								0	
Per patient costs - support								0	
Per patient costs - discharge								0	
Other - maintenance								0	
Total outflow	0	0	0	0	0	0	0	0	
Savings - in-patient								0	
Savings - emergency dep.								0	
Savings - home visits								0	
Savings - primary care								0	
Savings - long term care								0	
Other								0	
Cost savings	0	0	0	0	0	0	0	0	
Net annual cashflow	0	0	0	0	0	0	0	0	
Net cumulative cashflow	0	0	0	0	0	0	0	0	

Fig. 11 Cash flow analysis table for the Ambient Rehabilitation Kit compared to conventional caregiving method

the calculation period to seven years. As a result, a comparison table between conventional care methods and the Ambient Rehabilitation Kit solutions is designed which takes every factor during the care process into consideration in a seven-year period (see Fig. 11).

In order to define the scenarios for the comparison, a workshop was organized among the key partners within the REACH project and beyond, including medical device manufacturers, professional caregivers, and business consultants. The workshop participants co-created three suitable comparison scenarios for the Ambient Rehabilitation Kit (e.g., home and community prevention, hospital rehabilitation, care home solution). The data inputs for this CBA were acquired via market search and interviews with professional care providers.

Based on the results of the cash flow analysis table of the three scenarios, key financial indicators for each scenario can be calculated based on the following equations:

- BCR = (|present value of benefits|)/(|present value of costs|)
- ROI = (total cost savings – total outflows)/(|total outflows|)
- PBP = n + (|net accumulative cash flow of year n|)/(net annual cash flow of year $n + 1$), where n represents the number of the final year with negative net accumulative cash flow
- IIV = (initial hardware cost) + (initial deployment cost)
- NPV = (net annual cash flow)/(1 + cost of money)$^{\text{Years in the future}}$

Later on, sensitivity analysis (i.e., what-if analysis) was also performed, which concluded that caregivers' pay rate is the most important factor to consider.

As a result, the Ambient Rehabilitation Kit overall can be recommended to the key beneficiaries in various scenarios (e.g., home and community prevention, hospital rehabilitation, care home solution) in Germany.[1] Furthermore, other implications of the CBA are worth noting here.

- Given that the assumptions for CBA made here are relatively conservative, as the production number increases and manufacturing cost lowers over time, it is expected that the cost can be reduced further.
- This CBA only calculated mostly the direct benefits of the Ambient Rehabilitation Kit. More importantly, other social benefits of the proposed system that were not directly calculated here are also worth mentioning, such as improved quality of life and liberated productivity from both formal and informal caregivers.
- When transferring the developed technology to other markets outside Germany, the corresponding CBA based on the local market and situation will be necessary.
- Furthermore, researchers and entrepreneurs beyond the REACH project can also benefit from the proposed methodology to conduct their CBA of smart furniture and smart home solutions for various scenarios in aging society. Due to the lack of research on the CBA of smart furniture solutions for aging society, the results of this CBA will provide first-of-its-kind insights for the wise use and efficient allocation of smart healthcare resources in aging society.

3.7 Towards an Elderly-Oriented Smart Furniture Solution in China: A Survey and an Action Plan (Act)

Population aging is one of the major challenges not only facing the developed countries but also threatening many emerging economies. Specifically, China's upcoming aging society caused by various factors will pose an imminent threat to its future development. Therefore, a variety of measures must be taken to achieve its demographic sustainability. Smart home technology has gained substantial popularity over the past decade. It also started to show its prominence in the fields of aging in place and home care for older adults. Smart furniture can be considered as a novel subcategory of smart home technology. However, gerontechnology research in China is still lagging behind compared to developed countries such as the USA, Germany, and Japan. Specifically, according to a study in 2015, China was still considered as an academic laggard in gerontechnology compared to leaders such as the USA and the UK, although it began to catch up in most recent years (Huang et al. 2015). At the same time, there is also a lack of research on the adoption of gerontechnology among Chinese older adults. Therefore, to conduct a survey to investigate their adoption, attitude, and preference for smart home and smart furniture technology will be helpful for the future implementation of these technologies.

[1] The detailed data analysis of the CBA can be found in Chapter 4 of the thesis "Ambient Rehabilitation Kit: Developing Personalized Intelligent Interior Units to Achieve Demographic Sustainability in Aging Society" by co-author R. Hu (https://mediatum.ub.tum.de/680889?show_id=1638907).

In the following sections, the opinion survey will be introduced, and its implications will be analyzed. Finally, a project action plan for implementing elderly-oriented smart furniture technology in China will be illustrated.

3.7.1 Survey Methods

The opinion survey to investigate the attitudes and opinions of Chinese older adults towards using smart furniture technologies based on the PI^2Us as an example is introduced. The survey was conducted via two main channels (e.g., mainly via WeChat app on smartphones and email links and in-person questionnaires as a supplement for users who do not use any smartphones or tablets). With over one billion active users only in China, WeChat provided an excellent platform to distribute the questionnaires. The survey consisted of 11 close-ended questions (see Table 1) related to the current situation of the participants and their opinion towards the smart furniture and relevant technologies for older adults, of which questions 8–11 were measured by Likert scale (Likert 1932). In particular, photos with descriptions of older adults using the PI^2Us were shown as an example of smart furniture to give the survey participants an intuitive impression of the appearance and functions of the PI^2Us. The questions were designed with principles of simple language, common concepts, manageable tasks, and widespread information (Converse and Presser 1986). The survey was kept short as much as possible, which can be easily finished by older adults in 3–5 minutes. The survey was pretested with several older adults before formerly sending out in order to optimize the understandability and order of the questions.

Once individuals' data is involved, protecting their data privacy will be critical. Therefore, the good practice for protecting individual privacy in the survey is reported as follows. First and foremost, the survey was conducted in a fully anonymous manner, meaning that information such as names, birth dates, addresses, and

Table 1 List of survey questions for the older adults

No.	Question
1	What year were you born?
2	What is your gender?
3	What area are you currently living?
4	What is your highest level of education (including enrollment)?
5	Where is your main place of residence?
6	Which of the following smart digital products have you used?
7	Which of the following smart home devices have you used?
8	What do you think is the ease of use of current technology products for older adults?
9	How interested are you in using smart furniture with health functions? (examples from the REACH project are given.)
10	How important are the following attributes to you for using smart furniture?
11	What do you think of the prospects of China's elderly-oriented smart furniture market?

resident identity card numbers were not collected. This approach excludes any possibility to identify any individual survey participant. Furthermore, in order to participate in the online survey, all the participants needed to give consent to provide their basic demographic information such as age, gender, province of residence, and level of education. In addition, the data collected from older Chinese citizens was stored in the server of Tencent within the territory of the People's Republic of China during the research, which was in line with the newly established Data Security Law of the People's Republic of China. After the analysis was completed, the data collected in this survey was securely deleted in the user account, which according to Tencent Questionnaire's user account policy means permanent erasure in the company's server. These measures are also in line with Guide on Good Data Protection Practice in Research (European University Institute 2019).

3.7.2 Survey Results

The survey lasted 45 days from January 7, 2021, to February 20, 2021. In total, 1313 questionnaires were sent out, and 403 responses were collected, of which 384 were valid, leading to an effective return rate of 29.2% (19 responses were removed due to reasons such as incomplete data). The average completion time for each participant was 4 min and 17 s, which well met the expectation for the questionnaire design. The vast majority of the older survey participants completed the survey without issues. Necessary guidance or explanation was provided to the participants if needed. In order to better perform the data analysis, the study categorized the survey subjects as the "young old" (60–69), the "middle old" (70–79), and the "very old" (80+) (Forman et al. 1992), because the current retirement age for Chinese workers is 60 for male employees and 55 for female employees. The analyses of the survey data including general analysis and cross analysis are shown as follows.

3.7.2.1 General Analysis

In general, 384 older adults from 26 out of the total 34 provincial-level administrative divisions of China provided valid questionnaires during the survey. As of the beginning of 2021, there are approximately 260 million Chinese older adults aged 60 and over (People's Daily Online 2021). Therefore, it can be calculated with a 95% confidence level that the survey can represent the Chinese older population with a margin of error (MOE) of ±5%, which is acceptable for categorical data in social research (Bartlett et al. 2001). The average age of the survey participants was 68.64 years old. Among these participants, 39.1% were male and 60.9% were female. The education level of the survey participants was relatively balanced, among which 49.5% had college degree or above and 50.5% had high school education or below. Regarding the places of residence, 75.2% of the survey participants lived at home either alone or with spouse, and 20.8% of them lived with their children. Only 0.8% of them were living in retirement homes or nursing homes. This phenomenon is likely because (1) over 90% of Chinese citizens own their homes (Kharas and Dooley 2020), and (2) in Chinese culture, aging in place is a common practice, and older adults tend to rely on family members for primary care in later life due to the cultural norm of filial piety (Bai et al. 2020), although living in retirement homes has started to pick up momentum in recent years.

Regarding the user adoption rate of personal smart devices (e.g., smartphones, tablets, PCs/laptops, wearables), 93.5% of the participants used smartphones. On the contrary, only 8.9% of them used wearables. A possible explanation could be the inadequate functionality and frequent need for charging for current wearables, which also suggests that the ambient sensing solution integrated in smart furniture could provide a good alternative to wearables. In this survey, 5.5% of the participants did not use any of these devices. Although admittedly it is likely that older adults who did not use any personal smart devices were under-sampled because the majority of the questionnaires were completed via WeChat app, it is fair to say the adoption rate of personal smart devices among Chinese older adults is satisfactory.

In terms of user adoption of smart home devices (e.g., smart speaker, smart TV, robot vacuum, pet robot, smart door lock, smart appliance, smart furniture, etc.), three quarters of the participants had experience with at least one of them, with smart TV having the highest adoption rate of 49.5%. On the contrary, smart furniture had the second lowest user adoption rate of 3.1%, only higher than companion robots. This is mainly because smart furniture is relatively a new field without many mature applications on the market. On the other hand, however, it also indicates a substantial market potential.

Regarding the usability of today's technology products for older adults, only 45.3% of the participants thought that they were easy or very easy to use. Therefore, improving the usability for older adults is highly important for developing new or improving current technology products.

When the interest in using elderly-oriented smart furniture was asked, examples of four PI^2U prototypes from the REACH project were given. As a result, 60.9% of the participants are interested or very interested in using elderly-oriented smart furniture. This indicates substantial interest and market opportunities for smart furniture among Chinese older adults.

In terms of the importance of various attributes in smart furniture, the survey participants valued the safety of the products the most (i.e., 85.4% of the participants find it important or highly important), followed by usability, quality, privacy protection, affordability, multifunctionality, and the aesthetics the least (i.e., 48.2%). This result indicates that when developing elderly-oriented smart furniture products for Chinese older adults, more attention shall be paid to aspects such as safety, ease of use, quality, privacy protection, and affordability.

Furthermore, most of the participants (i.e., 73.7%) reckoned that there will be a substantial market potential for elderly-oriented smart furniture in China, which further verifies the inference above.

3.7.2.2 Cross Analysis

This section focuses on analyzing the correlation between participants' demographics (e.g., age, gender, education level) and attitude towards smart home and smart furniture technology. The statistics were tested by Pearson's chi-squared test ($n \geq 40$) to evaluate the statistical significance between any two groups (Cochran 1952; Gravetter and Wallnau 2013).

Regarding the correlation between age and adoption rate, difficulty, interest, and expectations, there is a sharp decline in smart home technology adoption rate when the participants are older. In the "young old" group, 84.0% of the participants had experience in at least one smart home product, while in the "very old" group, only 35.6% had experience in using any smart home technology (Fig. 12-i). The

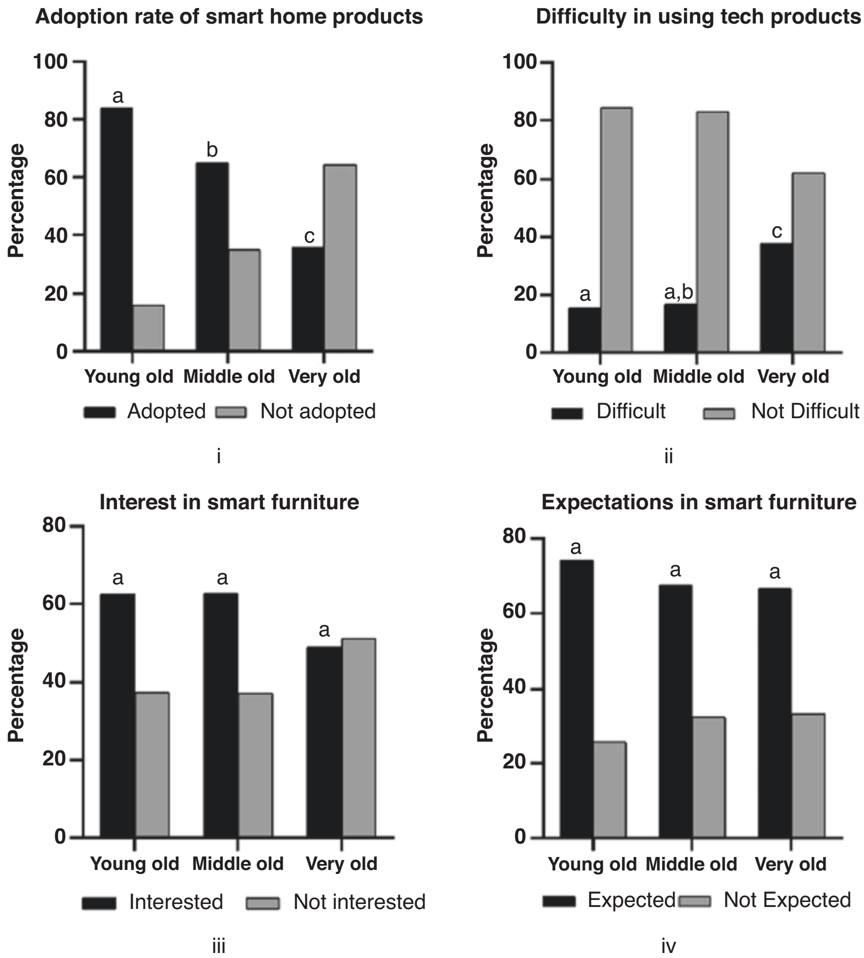

Fig. 12 Correlation between age and smart home technology adoption rate (the difference between any two groups sharing the same letters is not statistically significant)

differences between any two age groups are extremely significant ($p < 0.01$). Regarding the correlation between age and difficulty in using technology products (Fig. 12-ii), only around 15% of the older adults in both "young old" and "middle old" groups found it difficult or very difficult to use technology products ($p > 0.05$). However, the percentage is significantly higher in the "very old" group compared to the first two age groups ($p < 0.01$). Regarding the correlation between age and interest in using elderly-oriented smart furniture (Fig. 12-iii), more than 60% of older adults in the "young old" and "middle old" groups were interested or very interested in using the smart furniture developed in the REACH project. The percentage dropped slightly in the "very old" group, but no statistical significance can be observed between the "very old" group and other two age groups regarding user interest ($p > 0.05$). Therefore, the overall interest in using smart furniture is strong among Chinese older adults. Regarding the correlation between age and expectations in elderly-oriented smart furniture technology (Fig. 12-iv), all three groups of older adults expressed high expectations for its future market potential with no significant difference ($p > 0.05$).

Regarding the correlation between age and adoption rate, difficulty, interest, and expectations, it is impossible to observe statistically significant differences in the adoption rate of smart home technology, difficulty, and interest as well as expectation in elderly-oriented smart furniture between different genders ($p > 0.05$). Male participants seem to have slightly more difficulty in using technology products, although the difference is not statistically significant ($p > 0.05$) (Fig. 13).

Regarding the correlation between education level and adoption rate, difficulty, interest, and expectations, older adults with primary school education have a significantly lower adoption than those with any other education levels ($p < 0.05$) (Fig. 14-i). Regarding the correlation between education level and difficulty in

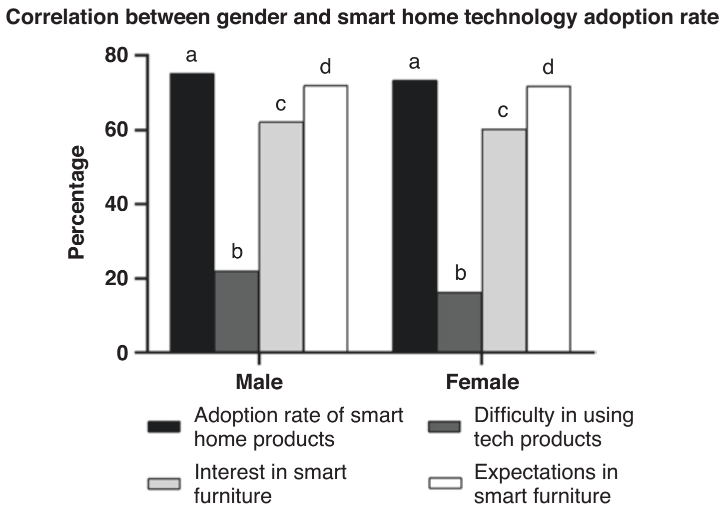

Fig. 13 Correlation between gender and smart home technology adoption rate (the difference between any two groups sharing the same letters is not statistically significant)

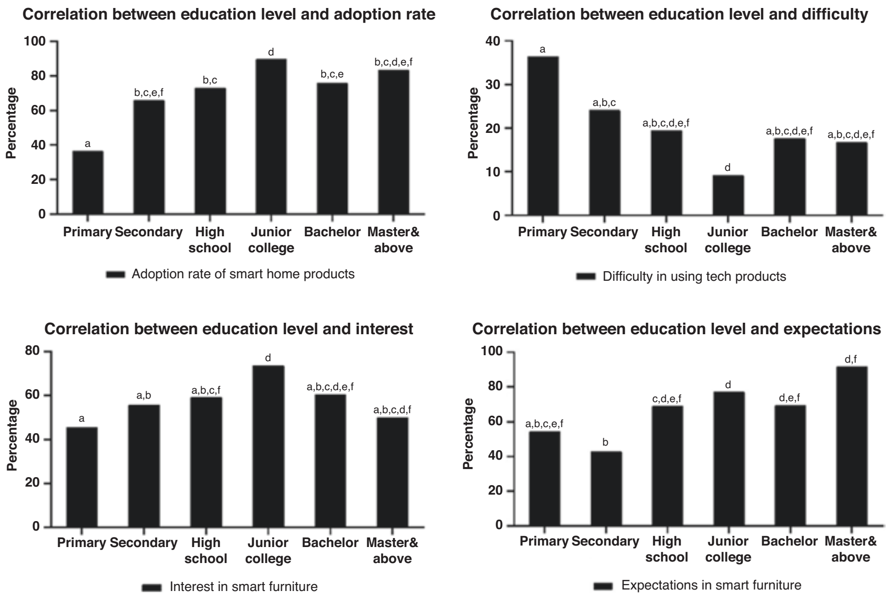

Fig. 14 Correlation between gender and smart home technology adoption rate (the difference between any two groups sharing the same letters is not statistically significant)

using technology products (Fig. 14-ii), older adults with education level lower than high school find it significantly more difficult than those with junior college education ($p \leq 0.01$). Meanwhile, participants with junior college education have a significantly higher interest in using elderly-oriented smart furniture than those with high school education or below ($p < 0.05$) (Fig. 14-iii). Finally, the majority of most education groups (expect for secondary school) have high expectations for elderly-oriented smart furniture (Fig. 14-iv). In particular, older adults with junior college education or above have significantly higher expectations than those with secondary school education ($p \leq 0.01$).

The survey results show that there is a substantial amount of interest and optimism towards elderly-oriented smart furniture among Chinese older adults. Although living in retirement homes and nursing homes has started to pick up momentum, the focused application scenario for developing smart furniture technology in China shall be mainly homes due to cultural considerations. In the process of developing localized elderly-oriented smart furniture products for China, aspects such as safety, ease of use, quality, privacy protection, and affordability shall be prioritized. The digital literacy among Chinese older adults is decent, but there is a clear digital gap among older adults aged 80 or over and with a lower education level. As a result, it is important to close the digital gap especially for older adults over 80 years old and with a lower education level using measures such as improving safety, increasing ease of use, improving quality, ensuring privacy protection, and bringing down the costs. The method of this survey is highly adaptable and scalable and thus can be easily adopted by researchers in other regions.

4 Discussion

4.1 Summary

This chapter introduces a procedure model as the foundation to efficiently develop gerontechnological systems in a systematic manner. Based on the analysis of the state-of-the-art assistive smart furniture and smart home solutions and the requirements of older adults, a service system transforming clinical and care environments into personalized modular sensing, prevention, and intervention systems was proposed, encouraging older adults to become healthier through activities. As a result, a series of special smart furniture integrating advanced sensing and assistive technology (i.e., PI^2Us) were developed which seamlessly materialize the care concepts and functionality. Based on these devices, the Ambient Rehabilitation Kit concept integrating the abovementioned assistive technologies was proposed to create a unique interior living and care solution for older adults in different living environments. Accordingly, an approach for testing and exhibiting the system (i.e., "lab-field-showroom" approach) was proposed and executed. Furthermore, a practical framework for the economic evaluation of the gerontechnological solutions compared to traditional care methods was also proposed. In addition, the prospects for implementing the Ambient Rehabilitation Kit in the Chinese market are discussed, and a research and development action plan is suggested based on the findings of an opinion survey in order to tackle the severe challenge that rapid population aging poses to the social sustainability of emerging economies.

4.2 Limitations and Future Work

The work reported in this chapter acted as a springboard for the further iterations and enhancements of the Ambient Rehabilitation Kit. Nevertheless, there are a few areas that this development cycle has not yet fully addressed. The primary goals of the follow-up phase of this research will be to (1) improve the usability of the prototypes and grow the PI^2U family, (2) create an organization to carry out a sustainable business model for the abovementioned innovations, (3) manage intellectual property rights for the key outcomes, and (4) seek standardization of the methodology and components developed in this research in order to push them to the market in a sustainable way.

4.2.1 Optimizing and Expanding the PI^2U Family (Do)

In the future design iterations, the work priority will be focused on enhancing the user experience of the PI^2Us together with end users. In particular, attributes of the PI^2Us such as usability, quality, privacy protection, affordability, multifunctionality, and aesthetics need to be improved. In order to better appeal to older adults, persuasive design principles and behavior change techniques need to be applied in this process (Valk et al. 2017). Furthermore, PI²Us with additional functions and forms such as mobile robot, exoskeleton suit, and unobtrusive wearables will be developed to expand the PI²U family in order to appeal to a broader user group.

4.2.2 Business Strategy and Scalability (Act)

Innovative products can never be successful if they have no access to the global market, even if appreciated by experts. Establishing the appropriate business strategy is the key to success of an innovation. Therefore, key members of the project have already initiated a start-up (i.e., CREDO GmbH) which will serve beyond the project as an integrator of the developed products and services and a solution provider to well-defined market segments based on suitable business models. Currently, the start-up is cooperating with a large Chinese furniture manufacturer to develop localized and customized elderly-oriented smart furniture technology in order to tackle the challenges imposed by rapid aging society in China and beyond.

4.2.3 Intellectual Property Protection (Act)

In the first cycle of the development, an innovative Ambient Rehabilitation Kit comprising a series of original smart furniture devices was developed. Thus, suitable legal protection will be the key to continue the success of the products developed so far. In the next phase of the R&D process, the PI²Us (e.g., SilverArc, MiniArc, SilverBed, etc.) including their installation process and user interfaces shall be protected through industrial designs and utility patents in respective countries in order to better push the developed systems into the market and sustain the motivation of innovation.

4.2.4 Towards Standardization (Act)

The standardization activities play a crucial role in catalyzing not only the competitiveness and social impact of innovations but also the economic growth of society. Standardization in Germany only, for example, accounts for at least 0.9% of the annual economic growth (Blind et al. 2011). There are three levels of standardization bodies that can facilitate the standardization of innovations, which are national (e.g., DIN in Germany, ANSI in USA, SAC in China, etc.), continental (e.g., CEN in Europe), international (e.g., ISO, ITU, IEC, etc.). Based on the experience and know-how gained in this research, the technical committee ISO/TC 314 – Ageing societies has been established to develop standards and guidance to tackle global challenges imposed by aging society. Furthermore, in order to better suit the needs and preference of older adults, standards for developing Ambient Rehabilitation

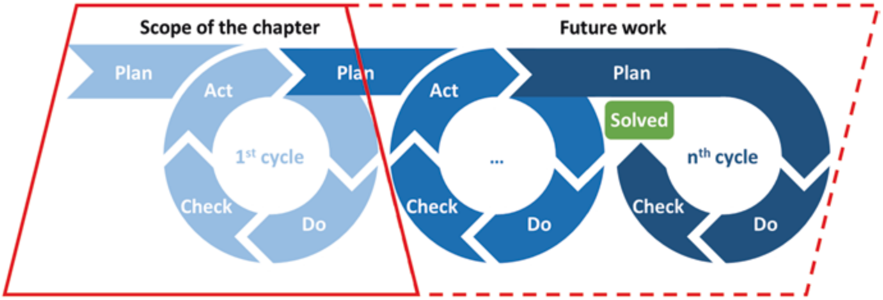

Fig. 15 Perpetual development cycle to adapt to the ongoing situation. (Figure redrawn and adapted from Christoph Roser at AllAboutLean.com, licensed under CC BY-SA 4.0, https://creativecommons.org/licenses/by-sa/4.0/)

Kits can be further formulated with different standardization bodies in other parts of the world to facilitate product localization and market optimization.

These ongoing or upcoming tasks comprise the crucial procedures of the future iterations of the proposed procedure model. The cycle will be repeated until the ideal solution is achieved (see Fig. 15). The case study reported in this chapter provides a valuable toolbox for researchers and developers to develop assistive technology for older adults and beyond in the future.

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