

# Towards a Distributed Intelligent Home Based on Smart Furniture for China's Aging Population: A Survey

R. Hu<sup>a</sup>, T. Linner<sup>a</sup>, S. Wang<sup>b</sup>, W. Cheng<sup>c</sup>, X. Liu<sup>d</sup>, J. Güttler<sup>a</sup>, C. Zhao<sup>a</sup>, Y. Lu<sup>e</sup> and T. Bock<sup>a</sup>

<sup>a</sup>Chair of Building Realization and Robotics, Technical University of Munich, Germany

<sup>b</sup>Institute of Preventive Pediatrics, Technical University of Munich, Germany

<sup>c</sup>Industrial Design College, Hubei University of Technology, China

<sup>d</sup>Sports Medicine Laboratory, Guangxi Normal University, China

<sup>e</sup>Department of Industrial Design, Eindhoven University of Technology, Netherlands

E-mail: [rongbo.hu@br2.ar.tum.de](mailto:rongbo.hu@br2.ar.tum.de), [thomas.linner@br2.ar.tum.de](mailto:thomas.linner@br2.ar.tum.de), [suting.wang@hotmail.com](mailto:suting.wang@hotmail.com), [wenting\\_cheng1984@126.com](mailto:wenting_cheng1984@126.com), [1171767934@qq.com](mailto:1171767934@qq.com), [joerg.guettler@br2.ar.tum.de](mailto:joerg.guettler@br2.ar.tum.de), [charlie.zhao@br2.ar.tum.de](mailto:charlie.zhao@br2.ar.tum.de), [y.lu@tue.nl](mailto:y.lu@tue.nl), [thomas.bock@br2.ar.tum.de](mailto:thomas.bock@br2.ar.tum.de)

**Abstract –**

Population aging is one of the major challenges facing the world. In particular, the advent of China's aging society caused by various factors will be a major threat to its future development. Therefore, serious measures need to be taken to achieve its demographic sustainability. Smart furniture can be considered as a novel subcategory of gerontechnology. One of the main outcomes of the EU-funded REACH project was a variety of smart furniture named Personalized Intelligent Interior Units (PI<sup>2</sup>Us) which served as the key component of a distributed intelligent home to promote the health and activity level of older adults. This outcome can potentially be a solution to mitigate the consequences caused by population aging. In order to understand the attitudes and opinions of Chinese older adults towards the relevant technologies, the authors conducted an opinion survey using the PI<sup>2</sup>Us as an example, which sampled more than 380 older adults in 26 out of 34 provincial-level administrative divisions of China. The survey showed that Chinese older adults in general have a highly positive attitude towards smart furniture and smart home technologies. Several other insights also can be revealed from the survey. Based on further analyses, the paper summarized why the elderly-oriented smart furniture and distributed intelligent home has the potential to thrive in China's market soon. Finally, a three-year project action plan for implementing localized solutions in cooperation with a large Chinese furniture manufacturer was presented.

**Keywords –**

Chinese older adults; Distributed intelligent home; Gerontechnology; Population aging; Smart furniture; Survey

## 1 Introduction

Population aging is one of the major challenges not only facing the developed countries, but also threatening many emerging economies. China's upcoming aging society caused by various factors will pose an imminent threat to its future development. Specifically, by the end of 2020, Chinese older adults aged 60 or over reached 264 million. Thus, innovative measures must be taken to achieve its demographic sustainability.

Gerontechnology (e.g., elderly-oriented smart home, wearables, smart furniture) is a cross-disciplinary research and development (R&D) field combining gerontology and technology that has gained substantial attention over the past decade, demonstrating its potential in the fields of aging in place and home care for older adults. However, gerontechnology research in China is still lagging behind compared to developed countries such as USA, Germany, and Japan. According to a study in 2015, China was still considered as an academic laggard in gerontechnology compared to leaders such as USA and UK, although it began to catch up in most recent years [1]. For the same reason, there is also a lack of research on the acceptance and adoption of gerontechnology among Chinese older adults.

Therefore, it would be valuable to investigate Chinese older adults' adoption, attitudes, and preferences for gerontechnology products including smart home and elderly-oriented smart furniture to guide the future implementation of these technologies in China. In the following sections, the opinion survey using elderly-oriented smart furniture as an example will be described in detail, and its results and implications will be analyzed. Finally, a project action plan for implementing localized distributed intelligent home in China will be proposed.

## 2 Methods

In this section, a distributed intelligent home solution based on smart furniture developed in the EU-funded research project REACH for the purpose of increasing the activity and independence level of older adults is introduced. Furthermore, based on the proposed solution, the opinion survey to investigate the attitudes of Chinese older adults towards using smart furniture technologies is detailed.

### 2.1 Smart furniture in context

The smart furniture devices exemplified in the context of this paper were developed in the REACH project, a large European interdisciplinary research project aiming at developing customized healthcare systems to promote older adults' activity level and independence. In REACH, a special type of modular smart furniture named Personalized Intelligent Interior Unit (PI<sup>2</sup>U) was developed, which seamlessly integrated various functions (e.g., unobtrusive sensing and monitoring, training/gaming, nutrition, AI assistant, etc.) into the different living environments. The PI<sup>2</sup>Us include but are not limited to SilverArc, MiniArc, SilverBed, and ActivLife (see Figure 1) [2].

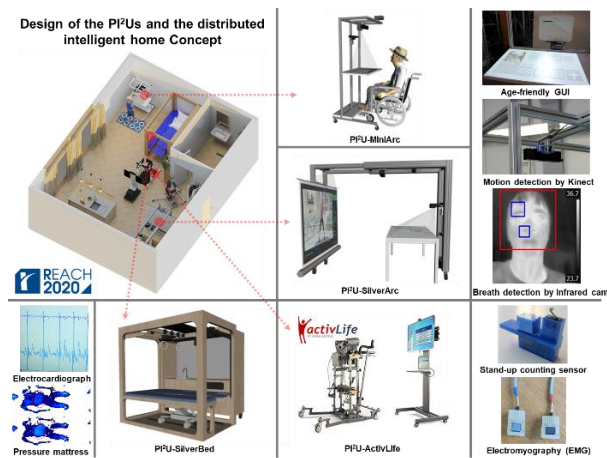


Figure 1. PI<sup>2</sup>Us with various sensors and the distributed intelligent home concept

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

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., 895mm). 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 Figure 2). In addition, an infrared camera can detect user's respiratory rate using machine learning.

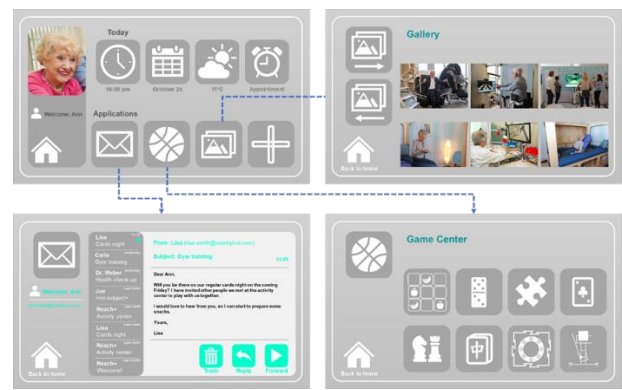


Figure 2. Elderly-friendly home screen and sub-screens of the SilverArc and MiniArc

The SilverBed is a carpentry-based modular bed incorporating a Sara Combilizer that assists older adults to move autonomously to a sitting, standing, or supine position in a comfortable and safe manner [3]. 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.

The 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<sup>2</sup>Us, a modularized smart home solution, namely the distributed intelligent home, was proposed, integrating the PI<sup>2</sup>Us 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 living environments such as home, hospital, and community in a flexible and adaptable manner (see Figure 1) [2].

Thereafter, all the data collected via a variety of

sensors integrated into the PI<sup>2</sup>Us (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/>, see Figure 3). The PI<sup>2</sup>Us, the distributed intelligent home concept, and the CARP platform were tested and validated in several exhibitions and tests across Europe later on.

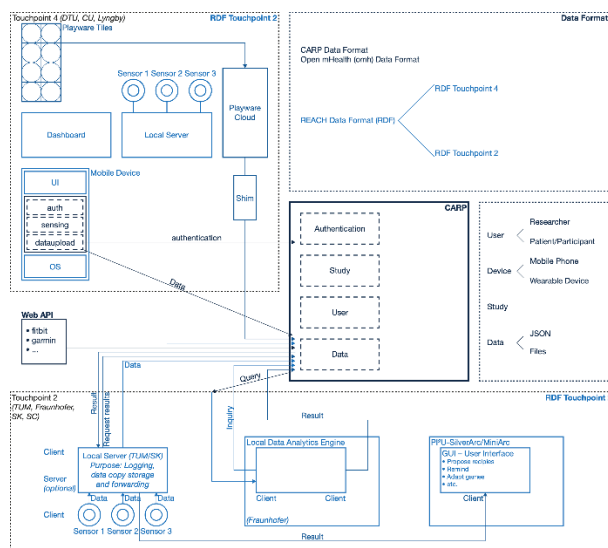


Figure 3. CARP's communication in REACH

## 2.2 Opinion survey

Based on the outcomes of the REACH project, a survey was conducted via two channels (e.g., mainly digitally via WeChat app and email, 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 a brilliant platform to distribute the questionnaires. The survey consisted of 11 close-ended questions that can only be answered by selecting from a limited number of options in order to investigate the current situation of the participants and their opinion towards the smart home technology for older adults (see Table 1). In particular, photos of older adults using various PI<sup>2</sup>Us were shown as an example of smart furniture to give the survey participants an intuitive impression of the appearance and functions of smart furniture. The questions were designed with principles of simple language, common concepts, manageable tasks, and widespread information [4].

Table 1. List of survey questions

No.	Question
01	What year were you born?
02	What is your gender?
03	What area are you currently living?
04	What is your highest level of education?
05	Where is your main place of residence?
06	Which of the following smart digital products have you used?
07	Which of the following smart home devices have you used?
08	What do you think is the ease of use of current technology products for older adults?
09	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?

Powered by Tencent Questionnaire (<https://wj.qq.com/>), the survey is designed in a user-friendly manner in order to appeal to older adults - the main audience of this survey. The survey was kept short as much as possible, which can be easily finished by older adults in 3-5 minutes. The survey was pre-tested with several older adults before formally sending out in order to optimize the understandability and order of the questions.

## 3 Results

The survey lasted for 45 days from January 7th, 2021 till February 20th, 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 minutes and 17 seconds, which well met the expectation for the questionnaire design. The vast majority of the survey participants completed the survey without issues. Necessary guidance or explanation were provided to the participants if needed. The results of the survey are revealed in detail as follows, including the general analysis and cross analysis.

### 3.1 General analysis

As mentioned above, 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 [5]. Therefore, it can be calculated that the survey can

represent the Chinese older population with a margin of error of  $\pm 5\%$ , which is acceptable for categorical data in social research [6].

There are many ways to categorize older adults by age. One study differentiated them as the young old (60-69), the middle old (70-79), and the very old (80+) [7], which is suitable for this study, because the current retirement age in China is 60 for male employees and 55 for female employees. The average age of the survey participants was 68.64 years old. Among these participants, 39.1% were male and 60.9% were female. Figure 4 shows the age (top) and gender (bottom) distribution of the survey participants.

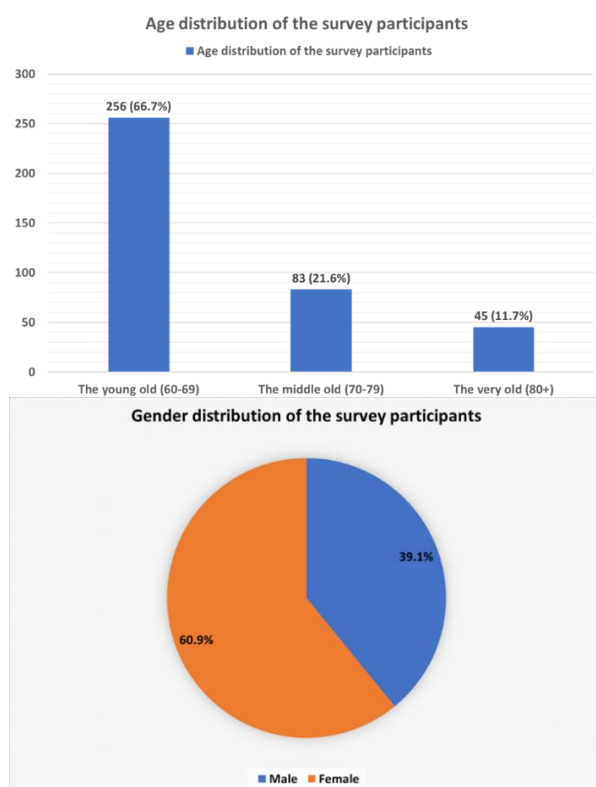


Figure 4. Demographics of survey participants (top: age distribution; bottom: gender distribution)

In general, the education level of the survey participants was relatively balanced, among which 49.5% had college degree or above (e.g., junior college, bachelor's, and master's degree) and 50.5% had high school education or below (e.g., primary school, junior high school, high school/secondary vocational school) (see Figure 5 top).

Regarding the places of residence, 75.2% of the participants lived 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 (see Figure 5 bottom). This phenomenon is likely because 1)

over 90% of Chinese citizens own their homes [8], and 2) in Chinese culture, aging in place (i.e., aging in home and community) 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 [9], although living in retirement homes has started to pick up momentum in recent years.

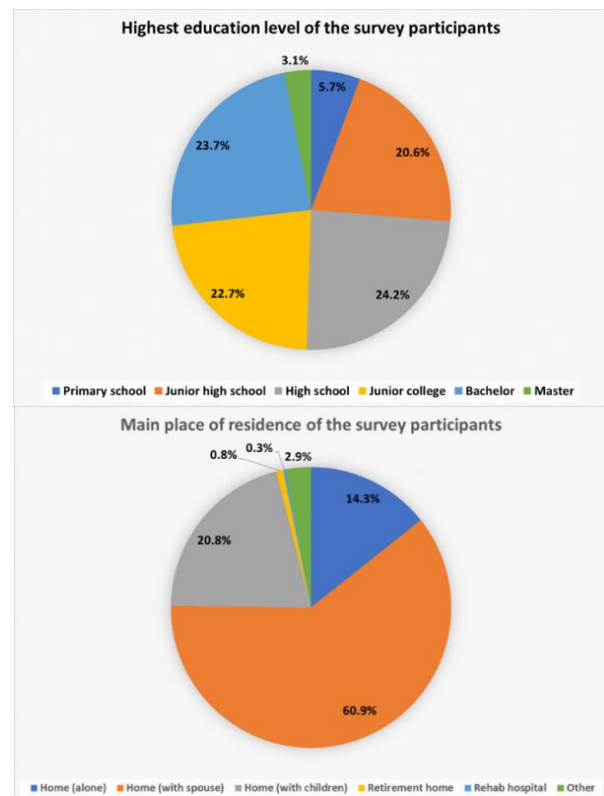


Figure 5. Education level (top) and main place of residence (bottom) of survey participants

Regarding the user adoption rate of personal smart devices (e.g., smartphones, tablets, PCs/laptops, wearables), 93.5% of the participants used smart phones. On the contrary, only 8.9% of them used wearables (e.g., Mi Band, Fitbit, Apple Watch, Samsung Galaxy Fit), see Figure 6. A possible explanation could be the inadequate functionality and frequent need for charging for current wearables. For example, one older adult from the survey complained that “the functions of the smart band are very limited, but it requires charging the battery every now and then. Therefore, it is a burden to use, so I abandoned it.” This phenomenon 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 personal smart devices were under-sampled because the majority of the questionnaires were



completed via WeChat app with a few exceptions of guided questionnaires, it is fair to say the adoption rate of personal smart devices among Chinese older adults is satisfactory.

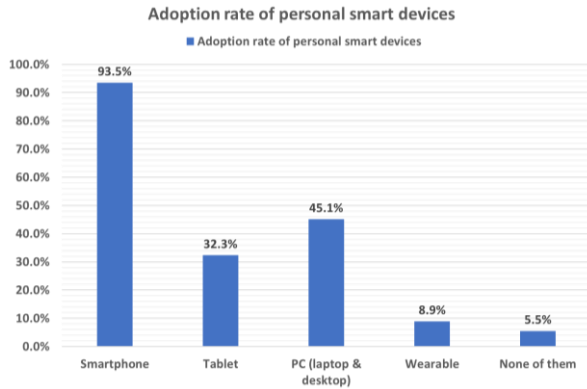


Figure 6. Adoption rate of personal smart devices

In the next question 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, see Figure 7). 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.

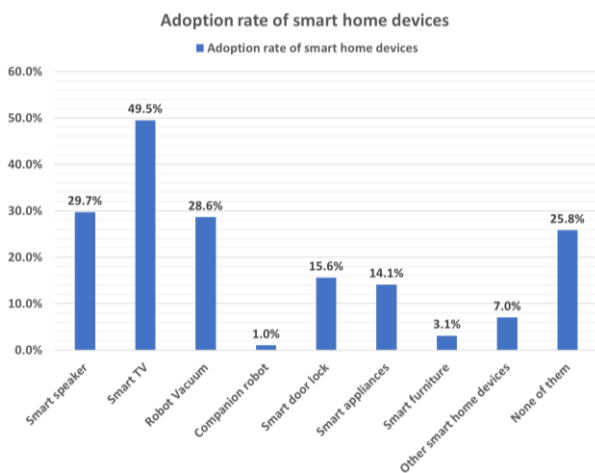


Figure 7. Adoption rate of smart home devices

Regarding the usability of current technology products for older adults, only 45.3% of the participants thought that they were easy or very easy to use (see Figure 8). Therefore, improving the usability for older

adults is highly important for developing new or improving current technology products.

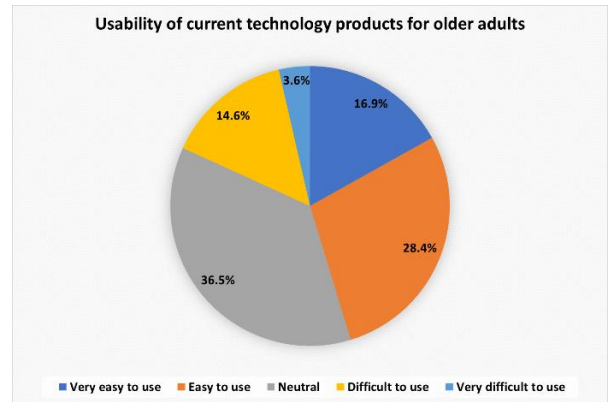


Figure 8. Usability of current technology products for older adults

When the survey participants' interest in using elderly-oriented smart furniture was asked, examples of four PI<sup>2</sup>U prototypes from the REACH project were given. As a result, 60.9% of the participants were interested or very interested in using elderly-oriented smart furniture (i.e., PI<sup>2</sup>Us). This indicates substantial interest and market opportunities for smart furniture among Chinese older adults (see Figure 9).

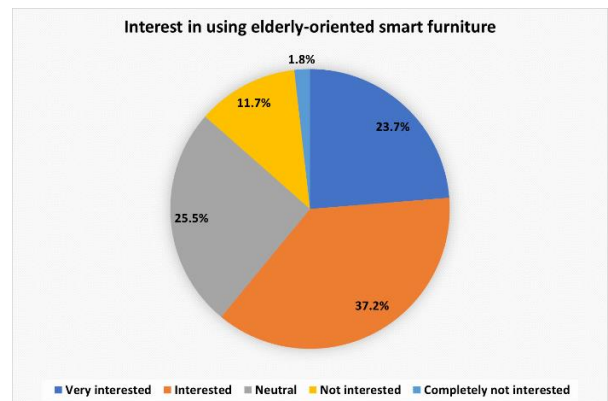


Figure 9. Interest in using elderly-oriented smart furniture

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 (i.e., ease of use, 77.8%), quality (75.5%), privacy protection (73.4%), affordability (70.6%), multifunctionality (50%), and the aesthetics the least (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 respectively, while aesthetics and multifunctionality are relatively of less importance. See Figure 10 for specific statistics.

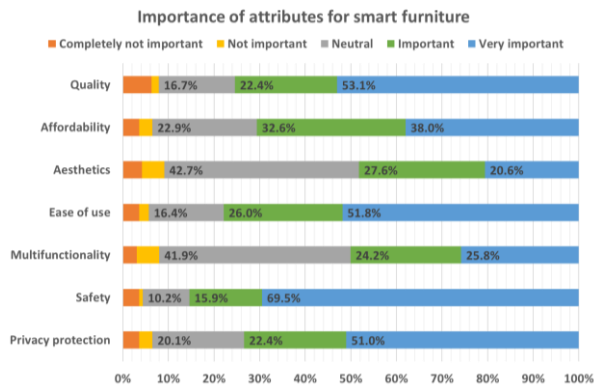


Figure 10. Importance of attributes for smart furniture

Regarding the final question of market potential, a vast majority (i.e., 73.7%) of the survey participants thought that there could be a substantial market potential for elderly-oriented smart furniture in China, which further verifies the hypothesis of this paper (Figure 11).

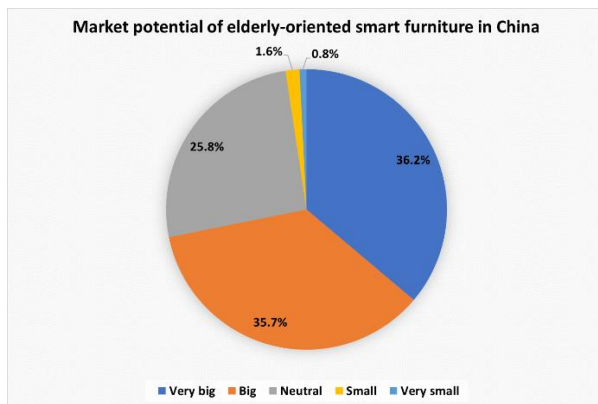


Figure 11. Market potential of elderly-oriented smart furniture in China

### 3.2 Cross analysis

This section focuses on analyzing the simple correlation between participants’ demographics (e.g., age, gender, education level) and attitude towards smart home and smart furniture technology.

#### 3.2.1 Age and adoption rate, difficulty, interest, and expectations

As shown in Figure 12, 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.

Regarding the correlation between age and difficulty in using technology products, only around 15% of the older adults in the “young old” and “middle old” groups found it difficult or very difficult to use technology products. However, the percentage more than doubled in the “very old” group.

Regarding the correlation between age and interest in using elderly-oriented smart furniture, 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 to 46.67% in the “very old” group, but still was close to half of that group. 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, all three groups of older adults expressed high expectations for its future market potential. The differences between three groups are not statistically significant.

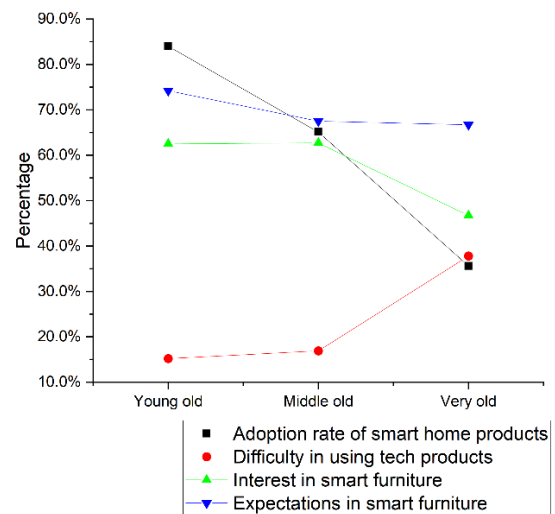


Figure 12. Correlation between age and adoption rate, difficulty, interest, and expectations

#### 3.2.2 Gender and adoption, difficulty, interest, and expectations

As shown in Figure 13, it is impossible to observe significant differences in the adoption rate of smart home technology, interest as well as expectation in elderly-oriented smart furniture between different genders, although male participants seem to have slightly more difficulty in using technology products.

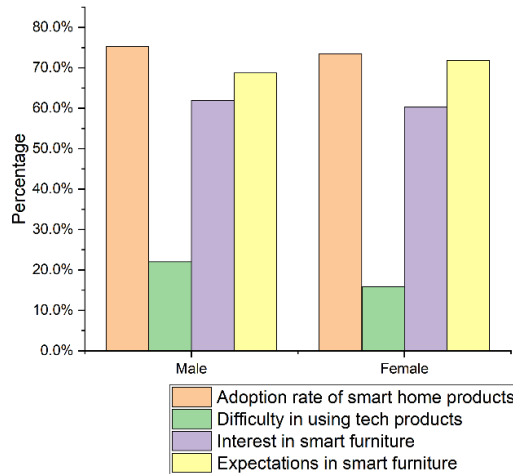


Figure 13. Correlation between gender and smart home technology adoption rate

### 3.2.3 Education level and adoption rate, difficulty, interest, and expectations

As indicated in Figure 14, older adults with higher education level tend to have a better adoption rate of smart home technology as well as higher expectations in elderly-oriented smart furniture. Participants with education level lower than high school seem to have more difficulty in using technology products. Meanwhile, participants' interest in using elderly-oriented smart furniture peaks among those with a junior college degree.

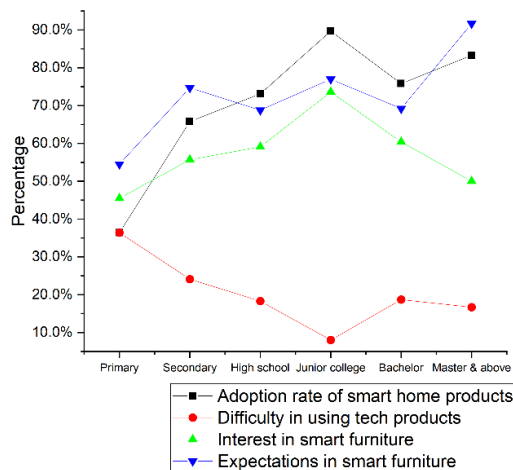


Figure 14. Correlation between education level and adoption rate, difficulty, interest, and expectations

## 4 Discussion

In this section, the limitations and implications of this survey are discussed. Furthermore, a three-year action plan for a project to implement smart furniture

technology in China is proposed.

### 4.1 Limitations of the survey

Like other surveys, this survey has certain limitations, although the overall conclusions are not affected. The main limitations are discussed as follows.

- The survey was conducted mainly in 26 out of 34 provincial-level administrative divisions in China. Several provinces were not covered by the survey. Furthermore, the number of older adults surveyed in each province was not proportional to the population of that province.
- The female to male ratio of the survey participants was around 6:4. According to the United Nations, as of 2019 the life expectancy of Chinese citizens was 76.9. However, the life expectancy of female citizens was 79.2, and that of male was 74.8, which led to a considerable gender gap of 4.4 years of age [10]. This phenomenon likely contributed to the gender imbalance of the survey participants.
- The vast majority of respondents answered the questionnaire via the WeChat app on smartphones. Older adults who were not able to use smartphones were likely under surveyed. In order to better reflect the opinions of older adults who do not use a smartphone, more on-site surveying after the COVID-19 pandemic will be preferred.

### 4.2 Implications and future work

Overall, 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 gain popularity, the initial focused application scenario for developing smart furniture in China shall be home and community 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 satisfactory but there is a clear digital gap among older adults aged 80 or over and with lower education level. As a result, it is important to close the digital gap especially for those over 80 years old and with lower education level by using measures such as improving safety, increasing ease of use, improving quality, ensuring privacy protection, and bringing down the costs. Furthermore, the method of this survey is highly adaptable and scalable, and thus can be easily adopted by researchers to other regions.

In conclusion, due to the promising survey results and other factors such as accelerated population aging process, growing middle class [8], unique culture of filial

piety [11], impact of the three-decade long “one-child policy” [12], decent digital literacy among older adults [13], state policy support [14], and catalyst of the COVID-19 pandemic, the smart furniture-based distributed intelligent home for aging society has the potential to thrive in China within the next few years.

The knowledge gained in the survey indicates that it is both necessary and promising to conduct further projects to implement elderly-oriented distributed intelligent home in China. Currently, several large Chinese furniture manufacturers showed interest and one already agreed to cooperate with the research team to promote the localization of the proposed technologies, which further proved the conclusion of the survey. Figure 15 shows the two-phase project action plan based on the Deming Cycle for developing localized elderly-oriented smart furniture technology in China. The results of the follow-up projects will be revealed in future publications.

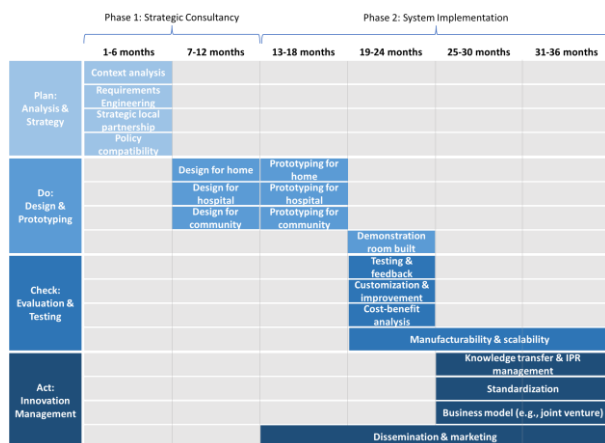


Figure 15. Three-year project action plan for developing localized smart furniture in China

## Acknowledgements

The research has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 690425.



## References

- [1] Huang, L., Zhang, L., Wu, F., Miao, H., & Li, X. International Comparison of Research on Gerontechnology (in Chinese). *Journal of Intelligence*, 34(10):22–27, 2015.
- [2] Hu, R., Linner, T., Trummer, J., Güttler, J., Kabouteh, A., Langosch, K., & Bock, T. Developing a Smart Home Solution Based on Personalized Intelligent Interior Units to Promote Activity and Customized Healthcare for Aging Society. *Journal of Population Ageing*, 13(2):257–280, 2020.
- [3] McWilliams, D., Atkins, G., Hodson, J., & Snelson, C. The Sara Combilizer® as an early mobilisation aid for critically ill patients: A prospective before and after study. *Australian Critical Care*, 30(4):189–195, 2017
- [4] Converse, J. M., & Presser, S. *Survey Questions: Handcrafting the Standardized Questionnaire*. Newbury Park, CA: SAGE Publications, Inc., 1986.
- [5] People's Daily Online. National Bureau of Statistics: 18.7% of the population aged 60 and above, the aging process has accelerated significantly (in Chinese). On-line: <http://finance.people.com.cn/n1/2021/0511/c1004-32100026.html>, Accessed: 26/05/2021.
- [6] Bartlett, J., Kotrlik, J., & Higgins, C. Organizational research: Determining appropriate sample size in survey research appropriate sample size in survey research. *Information Technology, Learning, and Performance Journal*, 19(1):43, 2001.
- [7] Forman, D. E., Berman, A. D., McCabe, C. H., Baim, D. S., & Wei, J. Y. PTCA in the Elderly: The “Young-Old” versus the “Old-Old.” *Journal of the American Geriatrics Society*, 40(1):19–22, 1992.
- [8] Kharas, H., & Dooley, M. *China's influence on the global middle class*. Online: [https://www.brookings.edu/wp-content/uploads/2020/10/FP\\_20201012\\_china\\_middle\\_class\\_kharas\\_dooley.pdf](https://www.brookings.edu/wp-content/uploads/2020/10/FP_20201012_china_middle_class_kharas_dooley.pdf), Accessed: 26/05/2021.
- [9] Bai, X., Lai, D. W. L., & Liu, C. Personal care expectations: Photovoices of Chinese ageing adults in Hong Kong. *Health & Social Care in the Community*, 28(3):1071–1081, 2020.
- [10] United Nations Development Programme. *Human Development Report 2020*. Online: <http://hdr.undp.org/sites/default/files/hdr2020.pdf>, Accessed: 26/05/2021.
- [11] Hsu, Y.-L. A Chinese response to the aging society. *Gerontechnology*, 14(4):187–190, 2016.
- [12] Hesketh, T., & Zhu, W. X. The one child family policy: the good, the bad, and the ugly. *BMJ (Clinical Research Ed.)*, 314(7095):1685–1687, 1997.
- [13] China Internet Network Information Center. *The 47th China Statistical Report on Internet Development (in Chinese)*. Online: [http://www.cac.gov.cn/2021-02/03/c\\_1613923423079314.htm](http://www.cac.gov.cn/2021-02/03/c_1613923423079314.htm), Accessed: 26/05/2021.
- [14] Zhang, Q., Li, M., & Wu, Y. (2020). Smart home for elderly care: development and challenges in China. *BMC Geriatrics*, 20(1):318, 2020.