

## Article

# Constructing a Smart Home for Future Elders toward All-around Happiness: Taking Connectivity as the Core Element

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**Abstract:** Smart homes, as one of the most prosperous industries of the Internet of Things, have tremendous potential in helping the elderly aging in place and dealing with the global aging society challenges. This study takes the needs of future elderly in China as a starting point and proposes that the core requirement of the aging group is “connectivity”, smart homes for older adults should assist them with connectivity establishment both physically and psychologically to improve their quality of life and help them live an independent, safe, and happy life in their older stage. The article defines the types of elderly connectivity needs as two main types and eight sub-connectivity, and further puts forward thirty smart home subsystems and their implementation elements. Moreover, the research applies the Kano model and questionnaire survey to provide the empirical proof of those thirty smart home subsystems based on the analysis of 371 questionnaire responses. Last but not least, we construct a five-layer architecture and abstract four principles on the connectivity building of a smart home for future Chinese elders. The research explores the possibility of building a wide range of connectivity and all-around happiness smart home environment for future elderly, which provides significant insights and an important reference for both the smart home industry and the pension industry.

**Keywords:** smart home; future elders; Chinese; connectivity; internet of things; all-around happiness; quality of life; positive psychology; PERMA model; Kano model

## 1. Introduction

The most significant social transformation in the 21st century is the increase in the aging population [1]. Due to the low birth rate and longer life expectancy, a large number of countries in the world are currently facing the challenges of an aging society [2]. China is one of the countries with the fastest aging process all over the world [3]. In 2020, China’s elderly population over 60 years old will reach 248 million, and the proportion of the elderly population will reach 17.17%; In 2025, China’s population over 60 years old will reach 300 million, which will make China become an over-aged country. By 2035, China will have 400 million older adults, and by 2050, this data will reach 487 million, accounting for 34.9% of the total population [4]. As one of the countries with the largest population base in the world, the rapid aging process and large base of the aging population will bring huge pension and economic pressure to the government and the whole Chinese society [5]. Generally speaking, the form of the pension in China is mainly divided into three types: social pension, institutional pension, and home pension [6]. According to a survey, 90% of Chinese elderly choose to live their pension life at home after retirement [7]. However, with the advancement of age and decline of physical and social

functions, the conventional home environment will be hard to guarantee the independence and safety of the elderly's daily life and activities [8].

A smart home uses comprehensive wiring technology, network communication technology, security technology, automatic control technology, audio and video technology to build efficient residential facilities and home management system of schedule affairs to improve the safety, convenience, comfort, environmental friendliness and artistry for the home life [9]. The smart home has huge potential in helping the elderly age in place [10]. It can not only make up for the shortage of service labor in the pension industry [11], reduce manpower and time costs [12], but also can match the elderly's need with the service providers to give them more precise, efficient and high-quality services [13]. In addition, through the collection of elderly-related data in a smart home, a basic information database of the elderly can be built and will give important reference and foundation for the government to provide relevant assistance and policies to serve the aging group and reduce the burden of social pension [14].

However, there is a question we all need to take into consideration: For the elderly, is a smart home really a happy home? [15]. At present, the majority of the research and developers of a smart home are focused on technical fields [16], and little attention has been given from the user perspective [17]. At the same time, many types of research on the elderly field have focused on the physiological aspects, like healthcare [18], security and monitoring [19], fall detection [20], etc. These phenomena actually somehow reflect the essence that related industries and practitioners lack a deep understanding of the elderly needs and requirements. It is true that for the older adults, the biggest challenges are physical and safety issues, but with the improvement of living standards and medical standards, there are more and more healthy elderly people [21], their needs for spiritual life are getting stronger and stronger and somehow no different to normal people [22]. At the same time, the mental life of the elderly often determines their psychological health status, and the psychological state has a significant impact on the physical health of the elderly [23]. Loneliness and depression are often the real murderers behind the deterioration of the physical health of senior citizens [24,25]. Therefore, how to use modern intelligent technology to make up for the weakening of the physical and social functions of the elderly and create a home environment with all-round happiness and help them rebuild the connectivity with the external world is a very worthwhile topic while facing the global aging challenges. On the basis of previous research, this study emphasizes the concept of "new elders" population, taking "connectivity" as the core element of the whole article, and proposes that the key point of the design and development of a smart home for the elderly is to help them establish connectivity and reshape relationship with the external world both physically and psychologically. This research has explored the possibility of building an all-round happiness smart home for future elders in China.

The essay is arranged as follows: Section 2 is the literature review of the research status of the smart home and the typical theory used in this research, the PERMA model of positive psychology. Section 3 is to introduce the concept of "new elders" in China and give analysis and summary of the characteristics of this certain group; Section 4 proposes that the core of the design and development of a smart home for new elders is to help them build "connectivity" and discusses comprehensively how the smart home can help the "new elders" establish all-round happiness. This section divides the types of "connectivity" into "physical connectivity" and "psychological connectivity", which are further classified into eight sub-connectivity, based on this, thirty smart home subsystems and their relevant implements are derived. Section 5 introduces the Kano model and conducts empirical research to analyze the attribute, provide proof, and clarify the user preference and development priority of these thirty different subsystems. Section 6 discusses the construction of an all-around happiness home from five levels: intelligent perception layer, basic network layer, data processing layer, application layer, and centralized scheduling layer, also, in this part, four principles have been clarified for the connectivity establishment for the future elderly in a smart home. The last part, Section 7, is the summary and conclusions of the whole article.

## 2. Literature Review

### 2.1. Smart Home for the Elderly

The market maturity and popularity of smart homes are still low [26], and the aging adoption trend of the smart home industry is not obvious [27]. However, there is no doubt that a smart home would have a prosperous future and provide an effective solution for the global challenges of an aging society [28]. At present, many developed countries are already exploring the application of smart homes in dealing with the aging challenges, such as the United States, the United Kingdom, France, Italy, Japan, South Korea, etc. [29]. Many projects are in progress, with funding from international organizations and local governments.

In the United States, the “Aging in place” project at the University of Missouri in Colombia focuses on offering elderly long-term healthcare services in the home environment due to their choices [30]. Another project at MIT, called “The house of the future”, conducts qualitative and quantitative studies on the relationship of the elderly group with their living environment factors and builds a user model based on updating the machine learning data set [31]. Moreover, there is a smart home system called “ACHE” in boulder, which aims to optimize the usage of energy resources by realizing intelligent control of temperature, heating, and lighting with respecting the lifestyle and habits of its residents [32]. What is more, “GatorTech Smart House” in Florida, developed by Helal et al., equipped the home components including entrance door, bathroom, floor, mailbox, etc. with sensors and actuators and connected them into the online platform to try to provide a comfortable and safe home environment for the elderly [33].

In Europe, Gloucester’s Smart House project funding by the UK government aims to help the elderly suffering from dementia. The majority of items in the house are under continuous monitoring via sensors [34]. Another project called “The ENABLE” also focuses on the subject with moderate dementia and provide assistive technology to improve their quality of life [35,36]. Moreover, “CarerNet”, a project in the UK, proposes the concept of “hospital at home” and deploys telemedicine service for older adults, including emergency response, community health information, real-time monitoring, etc. [37]. In Netherland, a smart home system has been built to learn residents habits and make decisions by itself according to the subjects’ behavior pattern and daily routine and it can also measure the daily physiological signs such as blood pressure, blood sugar, mean arterial pressure, arrhythmia, lung capacity, body weight, body temperature, and body fat. The main purpose of this project is to promote the communication of seniors, caregivers, and service providers [38,39].

In some Asian countries, like Japan, smart homes usually apply assistive technologies to create a smart and comfortable environment for older adults to live at home and improve their quality of life. There are 13 smart home examples called “Welfare Techno-Houses (WTH)” built by The Japanese Ministry of International Trade and Industry [40,41]. In Tokyo, Andoh et al. have developed a system based on resident vital physical signs analysis including breathing, heart rate, body motion, etc. to monitor the sleeping status of seniors [42]. In Nara, Masuda et al. have designed a monitoring system to provide elderly physical data and daily life information for rehabilitation therapists [43]. Moreover, a smart home, designed by Dr. Matsuoka in Osaka, inserts 167 sensors in a home environment, including home appliances like refrigerator, TV set, rice cooker, air conditioning, and home furniture to detect the elderly’s activities and realize intelligent adjustment and control [44].

The discussion above is a part of typical smart home examples, and there are still plenty of other projects and research. However, to sum up, the majority of existing projects and research are mainly concentrated in the following five aspects. First, home automation. It aims to help people improve the comfort of the home environment. Second, energy usage optimization. It is to continuously monitor important parameters of the home environment and optimize the energy usage to realize energy saving. Third, emergency and accident prevention. This aspect is to use sensors network to monitor and predict home life and environmental hazards to reduce property and personal accidents. Fourth, healthcare. This function is mainly to help seniors cope with the reduction of physical functions

through intelligent technology, like perception and cognitive abilities. Fifth, health management and medical rehabilitation. This aspect is to monitor the elderly's mobility and physiological parameters through wearable biomedical sensors to provide health management and rehabilitation treatment.

It is true that the use of intelligent devices and sensor technology is the foundation of a smart home, and health and safety issues are one of the most concerned aspects of the elderly group. However, with unprecedented developments on the medical level, there is an increasing number of healthy elders and this group accounts for a large proportion of the whole elderly population [45]. In terms of spiritual and emotional life, their needs are no different from those of normal people. Older adults want an independent, safe, and decent life, they also need recognition and respect from the external world rather than being treated as a vulnerable group who needs additional help [46]. At the same time, the mental status of the elderly plays an important role in their physical health. Even before serious diseases, the psychological state exerts a significant effect on their health status [47]. So the research and developers of a smart home for seniors only laying emphasis on the technical part or home environment or healthcare indeed somehow loses the essence of elderly needs. Because these concerns mostly stay at the survival level and ignore the psychological needs and spiritual life of the elderly group. Some scholars have also noticed related issues and put forward that smart home should promote the socialization interaction of older adults and help them deal with the problem of isolation [29,48,49], but they fail to put forward the concept of creating a smart home for all-around happiness for the elderly and lack the in-depth exploration of relevant system construction.

This study argues that smart homes for the elderly should break through the traditional definition and impression of "helping the elderly" so that the elderly could get rid of the sense of being "monitored" and "served". The researchers and developers in the field of a smart home for the elderly should see some important phenomena: after the elderly's retirement, they lose their jobs and have increasingly less contact with society and the external world [50]. At the same time, as they get older, old people's physical functions such as perception and sensation have decreased year by year due to the growth of age. The double decline of physical function and social function has caused the separation of the physical and psychological connections of the elderly with the external world [51]. Thus, how to apply modern technology to help the elderly rebuild "connectivity" and create an independent, safe, happy home environment to improve their quality of life and all-round wellbeing is a question that all the smart home industry researchers and developers should take into consideration.

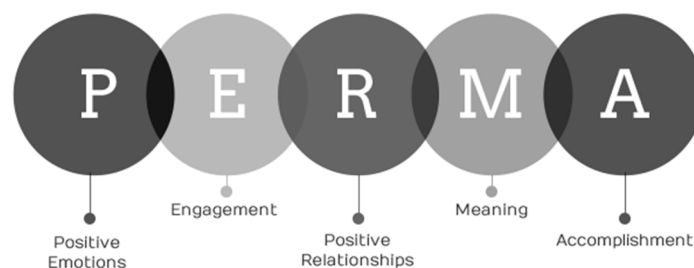
## 2.2. PERMA Model in Positive Psychology

Positive psychology is one of the latest branches of psychology, it mainly conducts research and proposes theories on the power and virtue to make individuals and communities thrive [52]. The theme of positive psychology is "happiness". Happiness is a seemingly simple but extremely complex concept. It is also a goal that humans have striven to own and pursue since ancient times. The PERMA model is a model of human psychological wellbeing. Martin Seligman, the "father of positive psychology" in the book *Flourish: A visionary new understanding of happiness and well-being* proposed it. As shown in Figure 1, it includes five aspects: P (positive emotion), E (engagement), R (relationship), M (meaning), and A (accomplishment). Martin Seligman points out that the overall happiness of man must be the vigorous development, full experience, and display in these five dimensions [53]. The specific contents are as follows:

- **Positive emotions:** Positive emotions are the foundation of happiness theory, which refers to the subjective feelings that can make us happy, warm, and comfortable. Life, which can successfully show these attributes, is called a pleasant life.
- **Engagement:** Engagement is a state when a person really enjoys and values doing something, he will devote himself to the moment and concentrate on doing it. In positive psychology, this state of involvement is called "flow".
- **Relationship:** Positive relationships include the forms of regular contact, communication, activities, mutual care, help, appreciation, and gratitude. These positive relationships allow individuals to be

listened to, comforted, encouraged, and reminded so that they have the ability to face difficulties and adversities.

- **Meaning:** Meaning is a personal sense of belonging, and this thing brings value beyond the individual. If people want to be happy, they must feel that their life is meaningful, worthwhile, and valuable.
- **Accomplishment:** A sense of accomplishment is the feeling of being happy or successful in what a person has done when they complete or finish something.



**Figure 1.** The positive psychology PERMA model.

The goal of this study is to construct an all-round happiness smart home framework for the elderly. Since the PERMA model profoundly reveals the five essential elements of happiness and being widely used in the happiness and well-being research field, we will also apply the PERMA model as one of the theoretical foundations in our research.

### 3. The Characteristics of Chinese New Elders

The definition of “new elders” will change with different influencing factors such as age, region, and population structure. This word was included in the “Chinese Language and Life Status Report” in 2010 [54]. The concept of “new elders” specifically refers to the elderly who have reached the legal retirement age but voluntarily insisted to work or actively participate in social activities. In this study, the “new elders” group in China is defined as the older people who still choose to work after reaching the legal retirement age, and being active in various stages of the society, generally refers to the age of 60 to 75 older adults with independent self-care skills. They mainly have the following characteristics:

- **In terms of physiology, longer life, and more chronic diseases:** The improvement of the quality of life and the level of medical care has led to the continuous extension of the average life expectancy of the elderly [55]. The health status of the elderly in China has generally entered a stage where chronic diseases and degenerative diseases are predominant. Most of them are healthy and energetic elderly people who have the ability to take care of themselves and do not need special care and concerns within a certain age period [56].
- **In terms of psychology, lonelier soul, and more social needs:** The parents of the first one-child generation in China have or will soon enter the rank of older adults [57]. With the acceleration of urbanization process, their children usually go to advanced cities and regions to receive a higher quality education and pursue their occupation career which will make the older generation live alone in their house or hometown [58]. In 2020, there will be more than 118 million elderly people living alone and in empty nests in China [59]. The strong emotional dependence on children and the reunion with the extended family make the elderly group have a stronger sense of loneliness [60]. The weakening of the traditional family support and the rapid development of social media has given rise to the need for social networking, entertainment, companionship, and spiritual comfort for the elderly.
- **In terms of consumption, more stable lifestyle and higher quality demand:** In addition to basic diet and medical treatment, the “new elders” group advocates freedom and pursuit of comfort, and maintains enthusiasm for tourism, fashion, beauty, fitness, food, leisure, entertainment,



and hobbies. They are willing to accept the development of technology and consume in order to improve their quality of life and strengthen their feeling of happiness and fulfillment [61]. The rise of this group has a huge impact on the traditional elderly consumption concept and market.

- **In terms of technology, an increasingly closer connection to the Internet environment:** The development of the Internet technology has laid a solid foundation for the promotion of the smart home industry. “The 45th Statistical Report on Internet Development in China” shows that, up until March 2020, the number of Chinese Internet users has reached 904 million, and the number of mobile phone Internet users has reached 897 million, the Internet penetration rate has reached 64.5% with an increasing percentage of 4.9 points comparing with the end of 2018 [62]. It can be seen that more and more middle-aged and elderly people are integrating into the Internet environment. The weakened living ability and social ability of the elderly need the assistance of intelligent products and services, they should rely on and be in need of technology more than the young people. Moreover, a considerable number of them have a fondness of technology [63].

#### 4. Smart Home Connectivity for New Elders

With the growth of age, the biggest transformation of the elderly group is the double decline of their physical and social functions [51]. It could result in the dual separation of their physical and psychological connections with the external world. Therefore, the core of the design and development of a smart home for the elderly is to help them rebuild and improve these weakening connectivity abilities. The objects of connectivity of smart homes for older adults include people, objects, environment, society, institutions, etc. For the type of connectivity, it can be divided into physical and psychological connectivity.

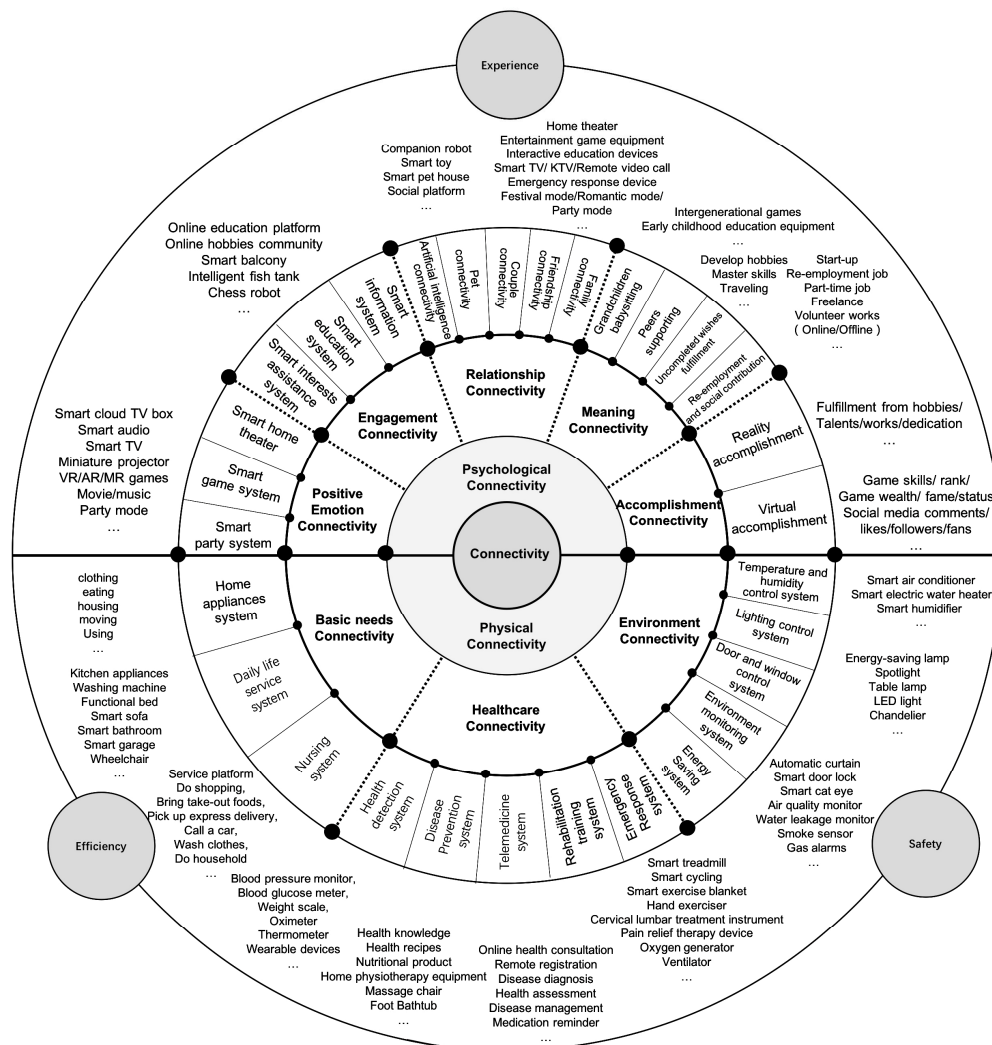
For physical connectivity, we mainly take Maslow’s hierarchy of needs into consideration and regard the two basic layers “Physiological needs” and “safety needs” as our important reference to construct the physical sub-connectivity of a smart home for the elderly [64]. Here we clarify three physical sub-connectivity, they are basic needs connectivity, health management connectivity, and ecological connectivity. The basic needs connectivity refers to the elderly’s ability to satisfy their physiological needs, like eating, drinking, moving, etc. Health management and environment connectivity mainly refer to safety needs, including internal safety which can be called health status and external safety which can be regarded as environment safety. In terms of psychological connectivity, Maslow’s hierarchy of needs indeed includes the psychological part, but it is not a typical theory for pursuing happiness and well-being. This study aims to explore how can smart homes help the elderly aging in place and achieve all-around happiness. Regarding this premise, we introduce the PERMA model from positive psychology and define the needs of psychological connectivity of the “new elders” for smart home as the following five aspects: positive emotions connectivity, engagement connectivity, relationship connectivity, meaning connectivity, and accomplishment connectivity [53], as shown in Table 1.

**Table 1.** The types of connectivity need of new elders.

Main Connectivity Types	Subcategory
Physical connectivity	Basic needs connectivity;
	Healthcare connectivity;
	Environment connectivity
Psychological connectivity	Positive emotions connectivity;
	Engagement connectivity;
	Relationship connectivity;
	Meaning connectivity;
	Accomplishment connectivity

After figuring out the basic classification about the connectivity needs of a smart home for the “new elders”, here come other questions: what is the detail content of this connectivity, and how does

the smart home establish these connectivity for the elderly group? This paper proposes an important framework, as shown in Figure 2, to answer these questions. The following will start from the eight sub-connectivity and conduct analysis and discussion about the derived thirty smart home subsystems in detail to help the elderly group improve the quality of life and create an all-around happiness home environment.



**Figure 2.** The connectivity system of a smart home for new elders.

#### 4.1. Physical Connectivity

The connectivity establishment of a smart home for the elderly will mainly revolve around three aspects, “efficiency”, “security”, and “experience”, as shown in Figure 2. However, the focus of physical connectivity should lay on the first two. It mainly includes the basic needs connectivity, health management connectivity, and the home environment connectivity.

#### 4.1.1. Basic Needs Connectivity

The main purpose of the establishment of basic needs connectivity is to improve the efficiency and experience of smart devices and service systems in five aspects, clothing, eating, housing, moving and using, to help older adults get rid of the heavy housework and live more independently. According to the different health status and self-care ability degree, we urge that the following three subsystems should be included: smart home appliance system, daily life service system, and nursing system.

- **Home appliances system:** The main function of the smart home appliance system is to improve the elderly's living efficiency and experience to reduce the barriers of usability and support them to take care of themselves. The intelligent control center performs unified management and connection of all the appliances to satisfy the elderly's needs from the following five aspects: clothing, eating, housing, moving and using, such as smart washing machine, smart kitchen, smart water boiler, smart function bed, smart sofa, smart bathroom, smart bathtub, smart shower head, smart garage, smart vehicle, smart wheelchairs, smart walkers, etc.
- **Daily life service system:** Daily life service system is suitable for the generally healthy elderly and those who have slight physical problems, such as the elderly whose leg and foot are somehow inflexible. They can rely on online Internet platform services to help them do shopping, bring take-out foods, pick up express delivery, call a taxi or car, wash clothes, do household, and some other daily life services.
- **Nursing system:** The nursing system is suitable for those who bear mild disability or short-term disability but could still live a home life with the help of equipment and light manpower assistance rather than going to a professional elderly care institution. Through convenient or special household appliances, coupled with the nursing services of third-party platforms, organizations, or short-term personnel care, they can manage their daily activities and maintain a home life.

#### 4.1.2. Healthcare Connectivity

For older people, health is one of their top concerns. Nowadays, the elderly group has gradually increased their emphasis on disease management and their acceptance level of smart devices has steadily raised. The connectivity of health management for the elderly includes five aspects: health detection system, disease prevention system, telemedicine system, training rehabilitation system, and emergency response system.

- **Health detection system:** On one hand, the health status of the elderly can be detected by building a system of household medical equipment combining physiological indicator detectors, such as electronic blood pressure monitor, blood glucose meter, weight scale, oximeter, thermometer, etc. On the other hand, we can insert monitoring sensors in different home furniture and use wearable devices such as smartwatches and pedometers to monitor and collect the health data of the elderly in time, so that the seniors can keep aware of their newest physical condition. At the same time, relevant data can be shared with their children, nursing assistant, private doctor, healthcare workstation, hospital, etc., and combined with the electronic medical records of the elderly for distracting diagnosis plan so that they can go to the hospital or make an appointment for a doctor's visit in time to receive diagnosis and treatment for any potential diseases.
- **Disease prevention system:** The elderly's awareness of healthcare has been increasingly improved in the progress of time. They are curious about health knowledge and are willing to invest in healthcare to prevent diseases in advance. Regarding this, the disease prevention system can reasonably recommend health knowledge, health recipes, and nutritional products to the elderly based on their own characteristics as well as some intelligent health equipment such as home physiotherapy equipment, massage chairs, foot bathtub, etc.
- **Telemedicine system:** On one hand, the pressure of the social medical system keeps increasing due to the rapid growth of the elderly population. On the other hand, more and more elderly people are surrounded by chronic diseases and there are a large number of them do not need to go to the hospital for treatment of their physical problems. Therefore, it is necessary to vigorously develop telemedicine and online medical care by using detective equipment and display terminal at home, combining with online platforms, to conduct online health consultations, remote registration, disease diagnosis, health assessment, chronic disease management, medication reminder, etc.
- **Rehabilitation training system:** Mild or serious illnesses are inevitable for the elderly with the growth of age. When serious diseases come, the elderly need to accept specific treatment and



training to rehabilitate, but if it is a mild illness or a chronic illness, daily rehabilitation training can be performed at home. So, this kind of demand should be supported in the smart home system. There could be some household smart equipment to help the elderly do basic rehabilitation training or exercise to maintain a healthy level at home, such as smart fitness equipment, including a smart treadmill, smart cycling, smart exercise blanket, hand exerciser, etc.; smart treatment equipment, including cervical lumbar treatment instrument, traction chair, hearing aids, etc.; smart rehabilitation equipment, like pain relief therapy device, functional bed, wheelchair, oxygen generator, ventilator, protective gear, sleep instrument, etc.

- **Emergency response system:** With the increasing number of empty nests and living-alone elderly people, if some sudden illnesses or fall happens when they stay at home, due to untimely discovery and missing the best treatment time, tragedy could happen and lead the elders to disability or death. Therefore, a remote monitoring system and an emergency response system should be set up to connect the elderly with their neighbors, family members, communities, and hospitals in a smart home to ensure that the elderly can get timely help and treatment.

#### 4.1.3. Environment Connectivity

Building connectivity in the home environment is mainly to help the elderly improve the comfort and safety of home life. Including the following five aspects:

- **Temperature and humidity control system:** This system aims to control the temperature and humidity of air and water in the home environment through temperature and humidity sensors to help older adults enhance the perception of environmental changes and do intelligent adjustments according to their needs. The relevant equipment and products include smart air conditioner, smart electric water heater, smart bathtub, etc.
- **Lighting control system:** It aims to realize intelligent control of all the home lights, including energy-saving lamp, spotlight, table lamp, LED light, chandelier, etc. For example, if an old man wants to go to the bathroom in the middle of the night, there is a risk that he may easily fall without light at the beginning, but with the lighting control system he can realize induction and sound control, or the system could even detect his behavior and help with the illumination automatically.
- **Door and window control system:** The system mainly includes automatic curtains, smart door locks, smart cat eyes, etc. The automatic curtains can help the elderly control natural light of the whole home environment intelligently, while smart door locks and smart cat eyes can be controlled by fingerprint recognition, face recognition, or iris recognition to control the entry and exit of personnel. It is helpful if the elderly forgets the key and can prevent unfamiliar strangers from entering the house.
- **Environment monitoring system:** The environment monitoring system could help elders ensure the safety of life, mainly including personal safety and property safety. For personal safety, the relevant functions of this system mainly include air quality monitoring, water leakage monitoring, smoke sensors, gas alarms, etc. With regard to property safety, surveillance cameras can be added into the home environment around the balcony, garage, doors, windows, etc. Additionally, the system can have connections and interaction with community security department or a police station to protect the home safety for elderly people.
- **Energy-saving system:** This system aims to monitor water and power consumption of the whole home system and use smart switches to realize relevant management and control. For example, when the elderly forgets to turn off some electrical appliances, the system can give intelligent reminders or cut off related equipment automatically to avoid waste of resources and prevent any possible accidents.

## 4.2. Psychological Connectivity

In terms of helping the elderly to establish psychological connectivity in a smart home, it mainly revolves around “experience” and “happiness”. We introduce the PERMA model in positive psychology, which was proposed by Martin Seligman [65], the father of positive psychology, as our theory basis. According to the PERMA model, we divide the new elders’ psychological connectivity needs of a smart home into five aspects: positive emotions connectivity, engagement connectivity, relationship connectivity, meaning connectivity, and accomplishment connectivity. The following discusses the methods and contents about how to shape the elderly’s psychological connectivity of smart homes from these five aspects.

### 4.2.1. Positive Emotions Connectivity

Positive emotions allow us to expand our cognition and build more available resources. It includes “happiness”, “interest”, “satisfaction”, “pride”, and “love”. The trait of “optimism” also plays an important role in this element [66]. Moreover, it can make people more resilient and resistant to depression [67]. Therefore, positive emotions and an optimistic attitude play a very important role in maintaining the psychological health of the elderly. The shaping of positive emotions in a smart home could be considered from the following three aspects:

- **Smart home theater:** The majority of the elderly have entertainment and leisure habits such as watching TV shows, listening to the radio, listening to music and opera, etc. Therefore, the house should be equipped with a home theater system to provide a pleasure amusement environment for older adults, including smart cloud TV boxes, smart audio, smart TV, miniature projector, etc.
- **Smart game system:** According to the elderly’s interests, the smart game system can provide some game equipment at home to satisfy the elderly’s gaming and social desire, such as smart mahjong table, smart chess machine, etc. It can also add somatosensory games equipment with fitness interactive effects and adopt virtual reality (VR), augmented reality (AR), and mixed reality (MR) to enrich their gaming experience at home. This system can not only consider providing entertainment experience for the elderly but also can insert some healthcare and rehabilitation game content to help them receive health education training, keep fit, and do exercise, it can even insert some VR traveling games to satisfy their desire to experience the outside world. This system can provide the elderly with plenty of possible services in the form of games.
- **Smart party system:** Interpersonal communication and entertainment is a very important aspect of generating positive emotions. A smart home system can set festival mode, party mode, birthday mode to promote interactions of elderly people with their family members and friends in different special or memorable times, for example, Chinese New Year. It can also provide the functions of controlling lights and music, supporting KTV activity, movie watching, online sports watching, and many other group entertainment activities to promote and improve the elderly’s social life.

### 4.2.2. Engagement Connectivity

The engagement, also called “heart flow”, can let people learn, grow, and feel unparalleled happiness from the things they are engaged in. In this state, people will lose a sense of time and space and concentrate on the task on their hands. Only when the individual skill level is high and the task difficulty is also high to match each other, can they reach the state of “heart flow”. In contrast, when personal abilities could not match the difficulty of the task, it may lead to boredom or agitation [68]. Therefore, the shaping of smart home engagement connectivity is to help the elderly to complete the works and tasks that suit their ability and let them enjoy the current tasks. We can try to build it from the following three aspects:

- **Smart information system:** This system aims to share the knowledge and information that the elderly are interested in, such as current affairs news, healthcare knowledge, etc., to help

them recognize the world, be familiar with their surrounding environment, and promote peer communication.

- **Smart education system:** The purpose of this system mainly aims to provide online courses for the elderly to help them carry out online education at home to train and improve their skills, such as fashion, makeup, square dance, calligraphy, painting, flower planting, etc., to help them master their interested skills and knowledge. At the same time, in addition to hobbies, some professional science courses which are of interest to the elderly can also be provided, even some older adults want to go back to university to receive higher education again and realize their value, a variety of needs could also be considered while building this system since education is always full of possibility.
- **Smart interest assistance system:** Older adults have various interests and hobbies. A smart home can be embedded with an intelligent interest assistance system to help them develop their hobbies. On one hand, we can produce related intelligent products to provide related auxiliary products for the elderly, such as intelligent fish tank, robot for chess and cards, smart TV for square dance, etc. On the other hand, we can use the Internet platform to build different communities for older people who share the same or similar interests and organize online and offline communication activities and competitions to promote their hobbies development and social interaction.

#### 4.2.3. Relationship Connectivity

A study indicates that what makes people happy in the end is not how much wealth and fame they have, but how deep and well connected they are to the people around them [69]. To some extent, human beings are social animals. Good interpersonal relationships enable people to understand, feel the benefits of being listened to, and gain comfort and encouragement. These are the keys to making the individual feel happy. For the elderly, due to the decline in social function, they are often trapped by loneliness and depression. They want to communicate with their children, get to know peers and friends, and find a sense of organizational belongings. These needs are particularly prominent for the elderly who are living alone or in an empty nest situation. Therefore, the smart home should also consider how to promote communication between the elderly and their children, the young generation, peers, community, organization and society, use online and offline methods to enrich the elderly's emotion and experience in love, friendship, and affection and help them integrate with the external world.

- **Family connectivity:** In a smart home, some devices that promote the interaction of the elderly and their family members, such as children and grandchildren, should be placed, like interactive home theater, multiplayer gaming equipment, interactive education product, festival mode of the home environment, etc. When their family members are not around, there should be some devices in smart homes to realize remote communication, such as voice calls, video calls, and emergency warnings.
- **Friendship connectivity:** Smart products and equipment which can promote social interaction for the elderly and their friends, neighbors, and peers should be added in-home environment. Compared to relatives and children who living away from them, the elderly's daily playmates and their neighborhood can respond much faster when the old people encounter some emergency situations and difficulties. Therefore, there should be some equipment in a smart home to connect the elderly with their friends and neighbors and promote the interactive assistance between their peers. At the same time, connecting older adults with those people who share the same hobbies and interests with them is also very important.
- **Couple connectivity:** For the elderly, their husband or wife is the person they have the closest connection at home. If any difficulties and problems appear in their life, they should be the first person to give support to each other. Therefore, the smart home should insert some devices and equipment to strengthen their communication and interaction. Some scenario models can be

established and set to promote their emotions and relationship. Additionally, it can provide some marriage and dating platforms to help elderly people who are living a single life to find their love. It can help them live a happier life and stay away from depression and loneliness.

- **Pet connectivity:** A large number of elderly people have the habit of feeding pets, and the companionship of pets is also a psychological comfort to the old adults [70]. So smart homes can consider adding some products for pets to help the elderly release the burden of feeding, promote their interaction, and increase mutual fun. The products could include smart pet houses, pet anti-lost GPS instruments, pet toys, etc.
- **Artificial intelligence connectivity:** Virtual contact is everywhere due to the development and popularity of the Internet in the contemporary world. We can vigorously develop companion robots and use robot technology to provide healthcare and services support for the elderly. In addition, pet robots, smart toys, and online virtual relationships can also exert their effects to play as compensation for the absence of some family members, friendship, and couple relationships for older adults [71].

#### 4.2.4. Meaning Connectivity

The meaning of life makes people feel a presence greater than the ego. Specifically, it is a kind of mind in which we are willing to give [72]. According to Duckworth, he regards this meaning as the purpose of life [73]. Most of these purposes are altruistic, in other words, the ultimate meaning of our lives, returning to its essence, will be related to helping others. For the elderly, when they have lost their dedication to work after retirement, they will lose their sense of direction and purpose of life. Hence, a smart home could try to help them gain these lost things again. Some considerations include the following four aspects:

- **Grandchildren babysitting:** In China, after retirement, the majority of elderly people will help their children to take care of their grandchildren which can help the elderly to increase their sense of belonging and value. Additionally, it can serve as an emotional dependence for the elderly after retiring. Therefore, we can launch some devices in smart homes to promote the interaction between the elderly and their grandchildren, such as early childhood education products, or insert some equipment to help them release the babysitting burden and improve the efficiency to do some relevant housework.
- **Peers supporting:** On one hand, the aging problem in China is becoming increasingly serious and there are insufficient staff and manpower in the pension industry. On the other hand, many retired elders are actually very healthy, they not only do not need any additional help but also have the ability to give support to their peers. Therefore, the smart home could mobilize these resources and promote the mechanism of interactive assistance between elderly people. Compared with intergenerational barriers, it is much easier for elderly adults to understand their peers' needs and support each other better.
- **Uncompleted wishes fulfillment:** After retirement, the elderly no longer have the burden and limitation of works, they have time and money to realize their wishes which they could not when they were young. They can try to find new goals and meaning for life, like developing their hobbies and mastering new skills and knowledge that they are interested in. A smart home can provide functions and services to satisfy their needs in these aspects, such as inserting online platforms and equipment to help the elderly learning new knowledge and skills, using virtual reality technology to help them experience and explore the outside world, etc.
- **Re-employment and social contribution:** Government and society should encourage elderly people to do start-ups, re-employment, freelance, part-time jobs, and volunteer activities and provide them with corresponding platforms and opportunities to integrate into society again. Because of the flourishing development of artificial intelligence and the internet industry, elderly people can do plenty of freelance and part-time jobs online while staying at home. For example,

the experience and knowledge of the elderly can be shared with society and young groups via online channels to bring more positive energy to the society, realize their own value and win the respect of others. Additionally, a considerable number of old people in China have the specialties and skills of traditional culture and art, so that we can make them the communicators of traditional culture and volunteers of cultural activities. Therefore, in a smart home, service, products, and platforms which could help to realize the re-employment and social contribution for the elderly can be considered.

#### 4.2.5. Accomplishment Connectivity

When we complete tasks that are meaningful to us, we will feel a great sense of accomplishment. This sense of achievement adds value to ourselves and helps us think we are valuable people [74]. The sense of achievement is important not only to make us more satisfied with our self-worth but also to allow us to be respected and recognized and gain higher status in the social environment. It is always the motivation for old adults to complete specific works and tasks. Therefore, the design and development of smart home should put emphasis on how to build the accomplishment connectivity for them, not only provide more opportunities but also enhance the feedback of the sense of achievement, which can be shaped in two ways:

- **Reality accomplishment:** The sense of real accomplishment is that the elderly are appreciated in the real world through their hobbies, talents, work, dedication, etc., and gain recognition and respect from others, even social status. Therefore, in smart home, we can provide services and products to support their relevant activities. For example, developing and promoting platforms for the elderly to do start-ups and innovation works.
- **Virtual accomplishment:** The sense of virtual achievement is particularly prominent in the current Internet era, such as the likes, comments, followers, and fans acquisition on different social media and the tasks and gains that older adults complete in the virtual computer game, like character rank, wealth, etc. These can help them achieve a sense of accomplishment. Therefore, smart home industry should also pay attention to the development of related products and contents to serve the elderly.

### 5. Empirical Research

From the analysis and discussion in Section 4, we acquired thirty subsystems of smart home to help the elderly building all-around connectivity, as shown in Table 2. In order to provide rational proof of these thirty subsystems and have a better understanding of the connectivity needs of Chinese future older adults, we need to investigate relevant content from a more general population. Thus, we conducted empirical research. A professional online-based survey service (Wenjuanxing) was accordingly implemented. The recruitment criteria should be: (1) participants should be familiar with the smart home appliance for more than one month; (2) participants should belong to different age groups; (3) participants' demographic information should be balanced. All the participants were initially informed of the general aim of this study and were informed that they could withdraw from the study anytime if there were any unsuitable or uncomfortable questions for them.

**Table 2.** Smart home subsystem items for new elders.

Item	Content	Item	Content
1	Home appliances system	16	Smart party system
2	Daily life service system	17	Smart information system
3	Nursing system	18	Smart education system
4	Health detection system	19	Smart interest assistance system
5	Disease prevention system	20	Buy for elder
6	Telemedicine system	21	Family connectivity
7	Rehabilitation training system	22	Couple connectivity
8	Emergency response system	23	Pet connectivity
9	Temperature and humidity control system	24	Artificial intelligence connectivity
10	Lighting control system	25	Grandchildren babysitting
11	Door and window control system	26	Peers supporting
12	Environment monitoring system	27	Uncompleted wishes fulfillment
13	Energy-saving system	28	Re-employment and society contribution
14	Smart home theater	29	Reality accomplishment
15	Digital game system	30	Virtual accomplishment

### 5.1. Demographic Information

In total, 371 participants were recruited in this survey. Of all participants, 162 were male while 209 were female. They were also asked whether they have heard, used smart home appliances, and bought some relevant products or equipment for elders or themselves. Detailed information can be found in Table 3.

**Table 3.** Sample demographic information.

Attributes	Value	Frequency	Attributes	Value	Frequency
Gender	Male	162	Heard	Yes	354
	Female	209		No	17
Age	Below 30	111	Used	Yes	290
	30–40	91		No	81
	40–50	75	Buy for elder	Yes	339
	50 above	94		No	32
Education	High school or below	4	Buy for yourself	Yes	342
	Undergraduate	362		No	29
	Postgraduate	5	Marriage	Yes	279
				Not	92

### 5.2. Smart Home Subsystem Attribute Analysis Based on the Kano Model

#### 5.2.1. Kano Model Theory and Questionnaire Settings

The Kano model, invented by Professor Noriaki Kano in Tokyo Institute of Technology in 1984 [75], is a useful toolkit for classifying and prioritizing user needs, examine the nonlinear relationship between the objective performance of products or services and people's subjective perceptions and satisfaction.

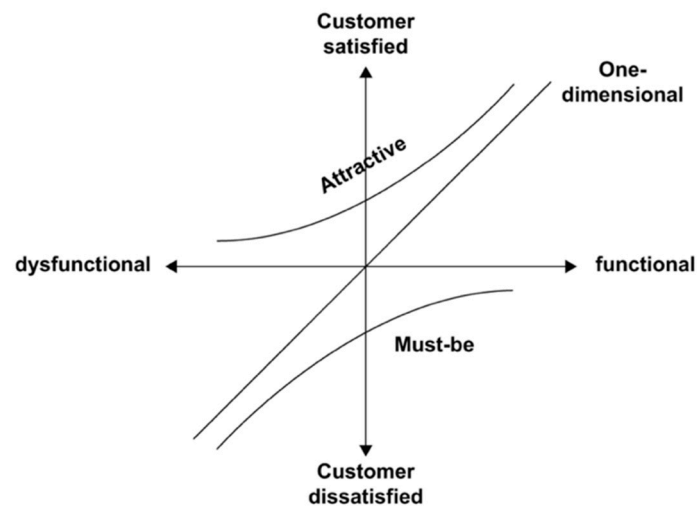


The nature of the Kano model was to construct an evaluation matrix ( $R$ ) on three dimensions: function, dysfunction, and importance:

$$R = \begin{bmatrix} r_{11} & \cdots & r_{1m} \\ \vdots & \ddots & \vdots \\ r_{n1} & \cdots & r_{nm} \end{bmatrix}$$

where  $m, n$  refers to various dimensions.

To specify, it has five basic attributes for specific assessment: must-be quality (M), one-dimensional quality (O), attractive quality (A), indifferent quality (I), and reverse quality (R), as shown in Figure 3. A must-be quality indicates that people might be very unhappy if a feature was not served, however, might not necessarily be happy if served. A one-dimensional quality indicates the specific feature is positively associated with people's satisfaction. An attractive quality indicates that the presence of a specific feature could significantly increase people's satisfaction while its absence does not have an influential impact. Regarding an indifferent quality, it means people's satisfaction does not have a fluctuation of the given feature. As for a reverse quality, it shows the relationship between people's satisfaction and the specific feature is negative.



Source: Kano *et al.* (1984)

**Figure 3.** The framework of the Kano model.

The survey for current research mainly contained two parts. The first one is demographic information, including gender, age, and education level, and the second part is the Kano survey of the thirty smart home subsystems for future new elders. To be more specific, participants have been given the specific hypothetical situation “When you became older” and would evaluate 30 different smart home features and select the most appropriate answer for each feature in both functional form and dysfunction form. Here we take our first feature, the “home appliance system”, as an example. The question sample is shown in Table 4. For each functional form and dysfunction form, there are five answers that can be selected: “I like it that way”, “It must be that way”, “I am neutral”, “I can live with it”, and “I dislike it that way”. The kano questionnaire for the 30 smart home subsystems shown in Table 2 can be seen in the Appendix A part in detail.

**Table 4.** Kano model functional and dysfunctional question sample.

Connectivity System	Question	Answer
Functional form	If the smart home has the home appliances system, how do you feel?	(1). I like it that way (2). It must be that way (3). I am neutral (4). I can live with it that way (5). I dislike it that way
Dysfunctional form	If the smart home doesn't have the home appliances system, how do you feel?	(1). I like it that way (2). It must be that way (3). I am neutral (4). I can live with it that way (5). I dislike it that way

Depends on the frequency of different answers and each feature matrix, all the features will have six different qualities according to the Kano model. We can see in Table 5, among them, M stands for must-be quality, O stands for one-dimensional quality, A stands for attractive quality, I stands for indifferent quality, R stands for reverse quality, and Q stands for questionable answers. In order to reflect appropriate weighting and variance, we followed the revised continuous analysis of the Kano model by Bill DuMouchel [76] and adopted this asymmetrical scale, starting from  $-2$  to  $4$ , as shown in Table 5. It focuses on the positive quadrant, which holds the strongest responses.

**Table 5.** Kano Evaluation Table.

Functional Form	Dysfunctional Form				
	I Like it That Way (−2)	It Must Be That Way (−1)	I Am Neutral (0)	I Can Live with it (2)	I Dislike it That Way (4)
I like it that way (4)	Q	A	A	A	O
It must be that way (2)	R	I	I	I	M
I am neutral (0)	R	I	I	I	M
I can live with it (−1)	R	I	I	I	M
I dislike it that way (−2)	R	R	R	R	Q

### 5.2.2. Smart Home Subsystem Attribute Evaluation

According to the Kano model, specific items of dysfunctional and functional was coded in Table 5. Importance was coded from “1 = not important at all” to “9 = Extremely Important”. Followed Bill DuMouchel's method [76], discrete and continuous analysis of attribute for smart home subsystems and dysfunction, function, and importance results were shown in Tables 6 and 7, Figures 4 and 5.

**Table 6.** Discrete Analysis of Attribute for smart home subsystem.

Item	Attribute Distribution (N (%))					
	M	O	A	I	R	Q
1	106 (0.29)	35 (0.10)	35 (0.14)	141 (0.38)	35 (0.10)	18 (0.05)
2	71 (0.19)	71 (0.19)	71 (0.19)	124 (0.33)	18 (0.05)	18 (0.05)
3	124 (0.33)	71 (0.19)	106 (0.29)	71 (0.19)	0 (0.00)	0 (0.00)
4	53 (0.14)	141 (0.38)	106 (0.29)	71 (0.19)	0 (0.00)	0 (0.00)
5	124 (0.33)	88 (0.24)	53 (0.14)	88 (0.24)	18 (0.05)	0 (0.00)
6	106 (0.29)	88 (0.24)	53 (0.14)	106 (0.29)	18 (0.05)	0 (0.00)
7	88 (0.24)	88 (0.24)	53 (0.14)	124 (0.33)	0 (0.00)	18 (0.05)
8	71 (0.19)	0 (0.00)	53 (0.14)	177 (0.48)	0 (0.00)	71 (0.19)
9	53 (0.14)	71 (0.19)	88 (0.24)	159 (0.43)	0 (0.00)	0 (0.00)
10	88 (0.24)	177 (0.40)	18 (0.05)	71 (0.19)	0 (0.00)	18 (0.05)
11	88 (0.24)	53 (0.14)	35 (0.10)	159 (0.43)	18 (0.05)	18 (0.05)
12	106 (0.29)	35 (0.10)	88 (0.24)	124 (0.33)	0 (0.00)	18 (0.05)
13	53 (0.14)	71 (0.19)	88(0.24)	106 (0.29)	0 (0.00)	53 (0.14)
14	88 (0.24)	106 (0.29)	71 (0.19)	106 (0.29)	0 (0.00)	0 (0.00)
15	159 (0.43)	88 (0.24)	71 (0.19)	18 (0.05)	0 (0.00)	35 (0.10)
16	71 (0.19)	71 (0.19)	53 (0.14)	141 (0.38)	35 (0.10)	0 (0.00)
17	106 (0.29)	71 (0.19)	53 (0.14)	124 (0.33)	0 (0.00)	18 (0.05)
18	71 (0.19)	141 (0.38)	71 (0.19)	71 (0.19)	0 (0.00)	18 (0.05)
19	124 (0.33)	18 (0.05)	88 (0.24)	88 (0.24)	0 (0.00)	53 (0.14)
20	35 (0.10)	35 (0.10)	71 (0.19)	212 (0.57)	0 (0.00)	18 (0.05)
21	71 (0.19)	88 (0.24)	88 (0.24)	88 (0.24)	18 (0.05)	18 (0.05)
22	71 (0.19)	88 (0.24)	53 (0.14)	106 (0.29)	35 (0.10)	18 (0.05)
23	18 (0.05)	53 (0.14)	53 (0.14)	159 (0.43)	35 (0.10)	53 (0.14)
24	53 (0.14)	71 (0.19)	18 (0.05)	194 (0.52)	18 (0.05)	18 (0.05)
25	53 (0.14)	106 (0.29)	53 (0.14)	141 (0.38)	0 (0.00)	18 (0.05)
26	106 (0.29)	106 (0.29)	35 (0.10)	88 (0.24)	0 (0.00)	35 (0.10)
27	71 (0.19)	53 (14)	88 (0.24)	124 (0.33)	0 (0.00)	35 (0.10)
28	88 (0.24)	35 (0.10)	88 (0.24)	141 (0.38)	0 (0.00)	18 (0.05)
29	88 (0.24)	35 (0.10)	71 (0.19)	159 (0.43)	0 (0.00)	18 (0.05)
30	53 (0.14)	53 (0.14)	35 (0.10)	177 (0.48)	35 (0.10)	18 (0.05)

Note: 1 = Home appliances system; 2 = Daily life service system; 3 = Nursing system; 4 = Health detection system; 5 = Disease prevention system 6 = Telemedicine system; 7 = Rehabilitation training system; 8 = Emergency response system; 9 = Temperature and humidity control system; 10 = Lighting control system; 11 = Door and window control system; 12 = Environment monitoring system; 13 = Energy saving system; 14 = Smart home theater; 15 = Digital game system; 16 = Smart party system; 17 = Smart information system; 18 = Smart education system; 19 = Smart interest assistance system; 20 = Family connectivity; 21 = Friendship connectivity; 22 = Couple connectivity; 23 = Pet connectivity; 24 = Artificial intelligence connectivity; 25 = Grandchildren babysitting; 26 = Peers supporting; 27 = Uncompleted wishes fulfillment; 28 = Re-employment and society contribution; 29 = Reality accomplishment; 30 = Virtual accomplishment.

**Table 7.** Continuous Analysis of Attribute for smart home subsystem.

	Item	Dysfunctional	Functional	Importance	Category
1	Home appliances system	2.22	1.65	6.80	M
2	Daily life service system	2.60	2.80	7.60	O
3	Nursing system	2.95	2.86	7.76	O
4	Health detection system	2.81	3.33	7.86	O
5	Disease prevention system	2.86	2.67	7.29	O
6	Telemedicine system	2.67	2.48	7.48	O
7	Rehabilitation training system	2.55	2.45	7.47	O
8	Emergency response system	2.18	1.94	7.47	M
9	Temperature and humidity control system	2.24	2.38	6.81	O
10	Lighting control system	3.40	3.00	8.00	O
11	Door and window control system	2.15	2.10	7.00	O
12	Environment monitoring system	2.35	2.20	7.40	O
13	Energy-saving system	2.22	2.56	7.67	O
14	Smart home theater	2.48	2.57	7.76	O
15	Digital game system	3.32	2.79	8.16	O
16	Smart party system	1.95	1.81	6.71	I
17	Smart information system	2.85	2.50	7.40	O
18	Smart education system	3.00	2.85	7.90	O
19	Smart interest assistance system	2.67	2.33	7.56	O
20	Family connectivity	2.00	2.05	6.80	A
21	Friendship connectivity	2.10	2.45	7.50	O
22	Couple connectivity	2.20	2.25	7.00	O
23	Pet connectivity	1.67	1.89	6.67	I
24	Artificial intelligence connectivity	1.85	1.55	6.50	I
25	Grandchildren babysitting	2.75	2.90	7.80	O
26	Peers supporting	3.16	2.74	7.42	O
27	Uncompleted wishes fulfillment	2.74	2.84	7.42	O
28	Re-employment and society contribution	1.90	2.05	6.70	A
29	Reality accomplishment	2.15	2.15	7.10	O
30	Virtual accomplishment	1.65	1.40	6.10	I

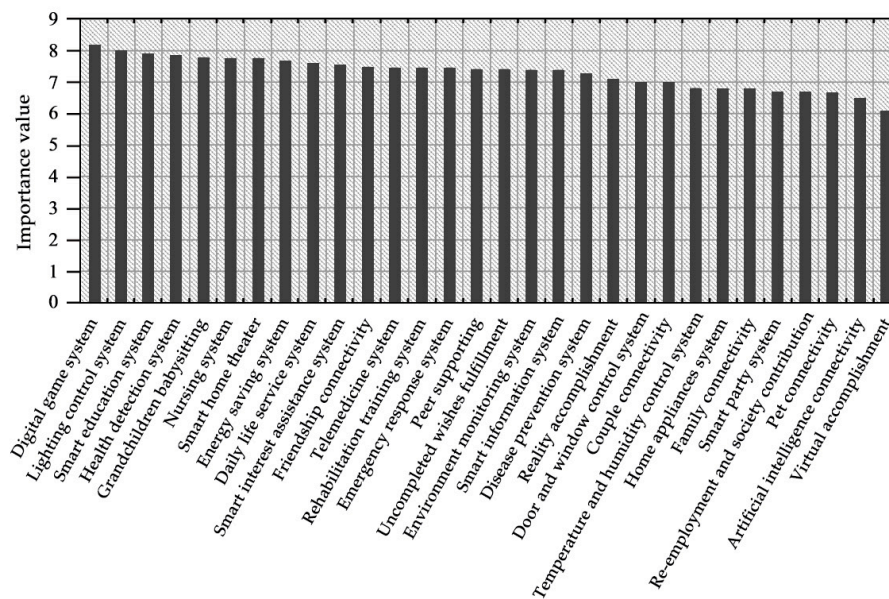
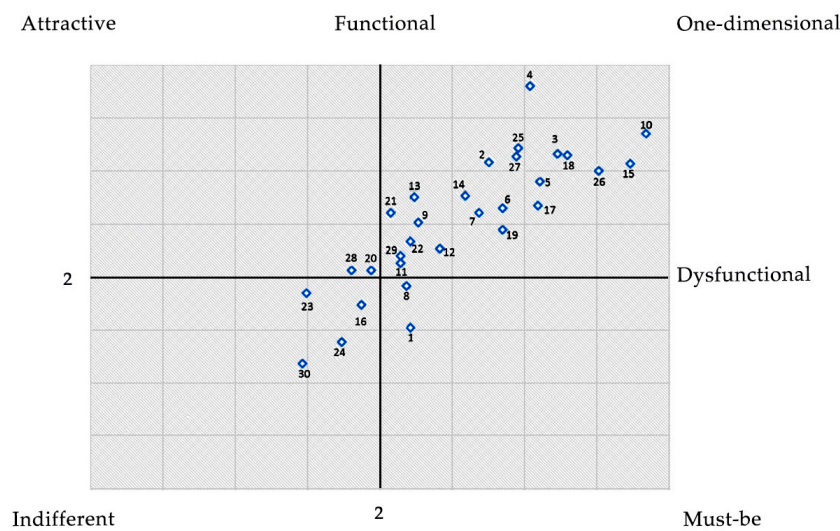


Figure 4. The importance distribution in the Kano Model.



Note\*: 1=Home appliances system; 2=Daily life service system; 3=Nursing system; 4=Health detection system; 5=Disease prevention system; 6=Telemedicine system; 7=Rehabilitation training system; 8=Emergency response system; 9=Temperature and humidity control system; 10=Lighting control system; 11=Door and window control system; 12=Environment monitoring system; 13=Energy saving system; 14=Smart home theater; 15=Digital game system; 16=Smart party system; 17=Smart information system; 18=Smart education system; 19=Smart interest assistance system; 20=Family connectivity; 21=Friendship connectivity; 22=Couple connectivity; 23=Pet connectivity; 24=Artificial intelligence connectivity; 25=Grandchildren babysitting; 26=Peers supporting; 27=Uncompleted wishes fulfillment; 28=Re-employment and society contribution; 29=Reality accomplishment; 30=Virtual accomplishment.

Figure 5. The attribute distribution in the Kano Model.

From Table 7 and Figure 5, we can see that most of the attributes of the thirty smart home subsystems belong to the “one-dimensional” category, occupying 73.3% of all the subsystem features, and the importance test result in Figure 4 indicates that all the features generally stay at a high importance value, which means that the majority of the smart home connectivity subsystems we have proposed cater to Chinese users' preference and expectation, and the more the system functions have, the higher the satisfaction of new future elderly to a smart home is. Among them, there are two “M” connectivity subsystems, namely “Home appliance system”, and “Emergency response system”, which shows that

for the future elderly, smart home equipment that can help them live more independently and the emergency response devices which can guarantee the safety of their lives and property are essential elements of the home environment for the aging group. There are two “A” connectivity subsystems, namely “Family connectivity” and “Re-employment and society contribution”. “Family connectivity” is classified as “A”, indicating that for the future Chinese elderly group, family relationship and connectivity is what they are very eager for. This aspect reflects the current status of Chinese elderly life, that is, many of them may live a lonely life or maybe in the status of loneliness and depression because of family members, children, or relatives separation, they are eager for social and communication. On the other hand, it also shows that a smart home can greatly improve elderly well-being and satisfaction if the design and development could make breakthroughs and actions in strengthening family connectivity. “Re-employment and society contribution” is classified as “A”. It reflects that, in the future, Chinese elderly people still have a strong desire to have a re-employment life and make contributions to society. Therefore, the services and products of a future smart home can also consider the development in this regard. There are four “I” categories, namely “Smart party system”, “pet connectivity”, “Artificial Intelligence connectivity”, and “Virtual accomplishment”, where “Smart party system” shows that Chinese people have few customs of holding party or gathering with their family and friends at home, thus they show low interests in home party mode, this is probably the difference between Eastern and Western cultures; “pet connectivity” shows that there is a considerable number of the population in China, at present, do not feed pets, so when they become older, they are not very concerned about this smart home subsystem; “Artificial intelligence connectivity” shows that the current Chinese users’ acceptance of artificial intelligence products stays low, and it is somehow difficult for them to accept the situation that they are surrounded or cared by robots or machine when they become older; “Virtual accomplishment” part shows that the majority of the current Chinese group, after they get older, still yearn for a sense of accomplishment in real life, and they do not have high expectations for the virtual achievement in the Internet or digital games. The above four “I” are the average profiles of all collecting responses in the study, but we do not rule out the possibility that these subsystems are loved or expected by some certain population groups. Meanwhile, customers’ consumption behavior and acceptance are variable. With the development of technology and the maturity of the market, the current differentiations may become attractive and one-dimension attributes in the future, so here we do not exclude their possibility of future development.

To sum up, the thirty smart home subsystems proposed in this article are generally in line with the user’s expectations for the future smart home, and the all-round happiness smart home system elements have been clarified for Chinese future elders.

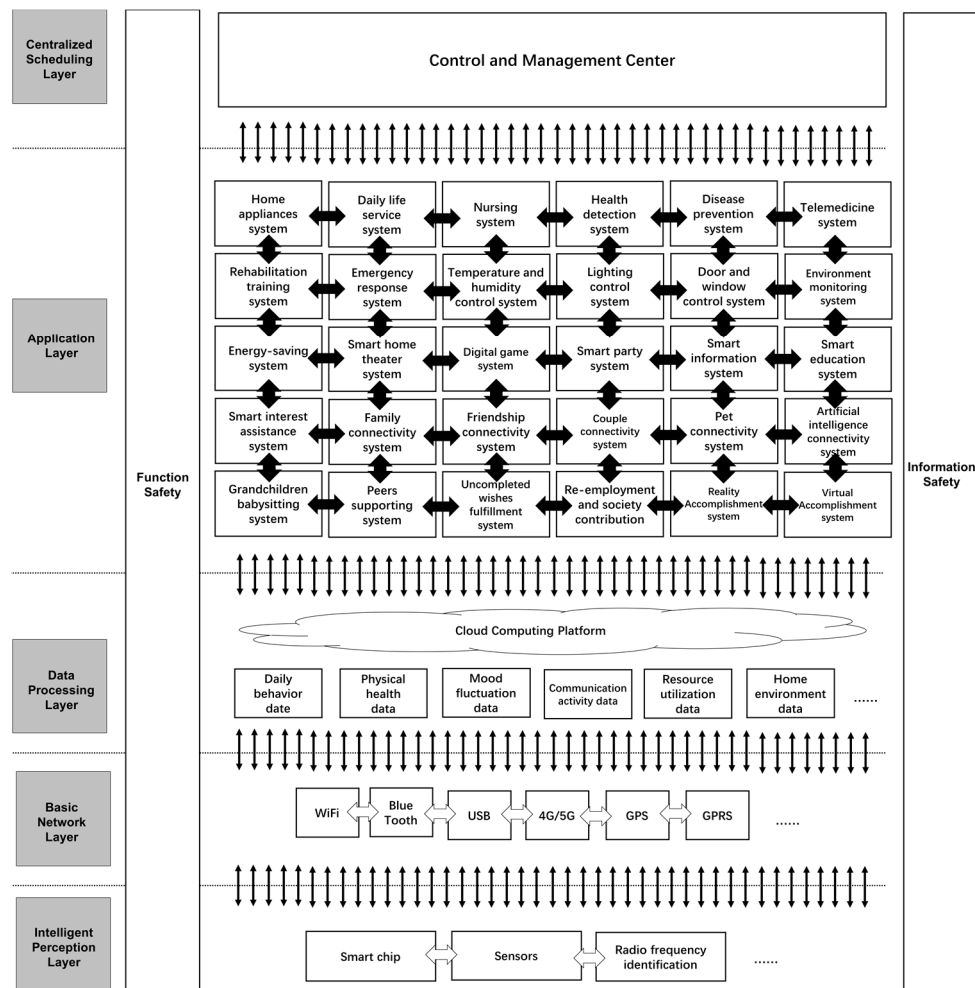
## 6. Construction and Principals of Smart Home System for New Elders

After the analysis of each connectivity and subsystem, the following, we will discuss the construction and principles of the smart home system for the future elderly.

### 6.1. Construction of Smart Home System

A smart home for the elderly is the organic integration of information technology, community development, residential operation mode, and the social pension system. It has the capabilities of automatic perception, rapid response, scientific decision-making, efficient processing, and considerable services. The goal is to provide an independent, safe, and happy home environment for the elderly. The technical architecture of the smart home is constructed in Figure 6 and mainly composed of the following five layers.





**Figure 6.** The construction of a smart home for new elders.

#### 6.1.1. Intelligent Perception Layer

The intelligent perception layer is the foundation of the whole smart home system. Through the smart chip, sensors, radio frequency identification, and other smart technologies inserting in the devices and home environment, data, and information collection on the physical state and activities of the elderly, the home environment and equipment operating status are realized.

#### 6.1.2. Basic Network Layer

High-speed, ubiquitous, highly reliable wired fiber-optic network and wireless network constitute the basic network layer of home devices and environmental facilities. This layer provides the channel to transmit the data collected by the intelligent perception layer to the data processing layer. Its reliability and transmission speed are the key to ensure that the elderly's home life data is transmitted in time and to get effective and precise feedback.

#### 6.1.3. Data Processing Layer

The elderly home life will generate a large amount of data, information, and knowledge, including daily behavior data, physical health data, mood fluctuation data, communication activity data, resource utilization data, home environment data, financial income, expenditure data, etc. So that the data processing layer is to conduct comprehensive processing and treatment of these data and form decision and command information. The accuracy and effectiveness of data cleaning and refining directly determine the accuracy of the commands to the relevant home system and equipment as well as the

quality of services for the elderly. Therefore, in this layer, a large amount of user data and behavior models to train the intelligent system and conducting machine learning is necessary.

#### 6.1.4. Application Layer

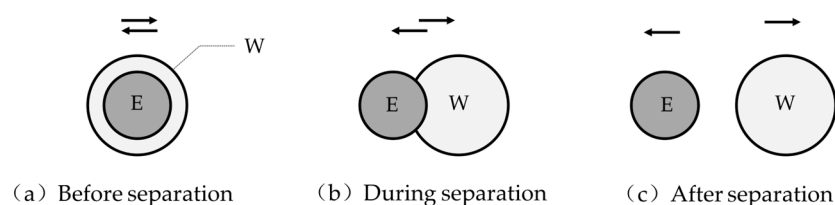
This layer consists of the thirty smart home subsystems which have been discussed and analyzed in the previous content of this article, which contains various home devices, systems, and service platforms, including home appliances system, daily life service system, nursing system, health detection system, disease prevention system, telemedicine system, training rehabilitation system, emergency response system, temperature and humidity control system, lighting control system, door and window control system, environment monitoring system, energy-saving system, smart home theater system, digital game system, smart party system, smart knowledge system, smart education system, smart interest assistance system, family connectivity system, friendship connectivity system, couple connectivity system, pet connectivity system, artificial intelligence connectivity system, grandchildren babysitting system, peers supporting system, uncompleted wishes fulfillment system, re-employment and society contribution system, reality accomplishment system and virtual accomplishment system. These systems realize the intelligent management and service of a smart home through intelligent algorithm analysis and effective decision-making based on the dynamic perception data of the elderly's home life, environment changes, and operating status of different devices, systems, and platforms. It is worth to mention that because the physical state and specific needs of different elderly people are different, the smart home can carry out modular development and provide personalized module customization services by combining different subsystems.

#### 6.1.5. Centralized Dispatching Layer

The smart home operation and management center is the integration and sharing of home environment and social pension service resources, opening up the island-style operation and dispatch of different smart home systems, pension service platforms, social support agencies, enterprises, and government departments, to achieve cross-functional, cross-business linkages, facilitate centralized processing, and command and respond to the needs of the elderly in a timely manner with resources management, distribution, and scheduling.

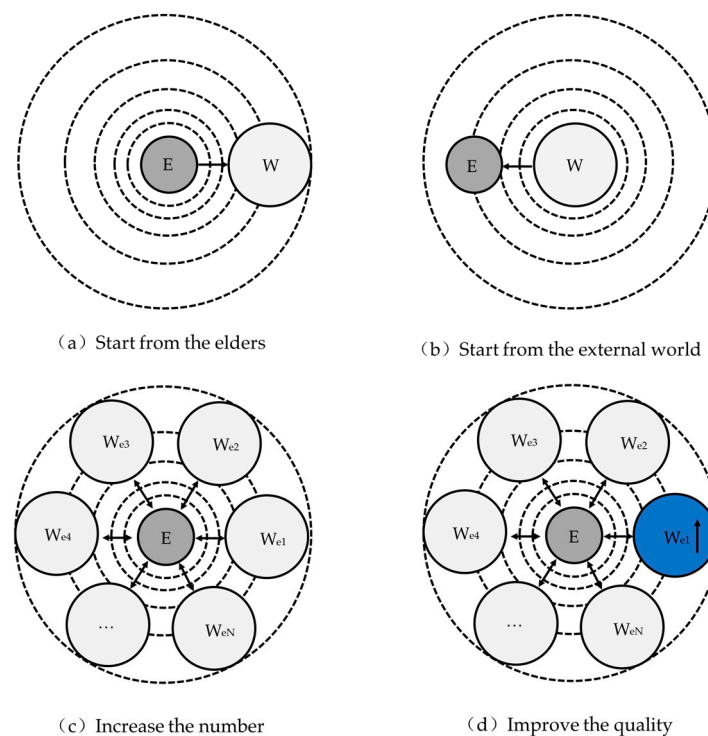
### 6.2. Principals of Building Connectivity

The natural evolution of the relationship between the elders and their external world is shown in Figure 7. The deep gray circle stands for the elders while the white stands for the external world. We can intuitively see that, in (a), while people are still young, they integrate with the external environment well because of education, works, family responsibility, etc. However, with the growth of age, in (b), older adults will be separated from the world somehow because of the decline of their physical function and social function. In (c), they totally separated from the world and were isolated because of the aging process. This a natural course and indicates why the connectivity establishment is so necessary for the elderly group.



**Figure 7.** The relationship separation process of the elders with the external world. Note: \*E = The elders; W = The external world.

According to the analysis above, we consider the principals of building connectivity from two aspects, the first one is, before the connectivity establishment, the smart home can provide equipment and products to strengthen the connection ability of the elderly or to reduce the barrier of relevant services to help senior group connect with the external world easily. Another aspect is that if the connectivity had already been built, then the smart home system could consider how to provide more opportunities for the connectivity establishment and how to improve the quality of established connectivity. According to the discussion above, we can summarize four principals as follows:



**Figure 8.** The four principals of building connectivity for the elderly. Note: \*E = The elders; W = The external world; We1-N = The external world element.

- Strengthen the elderly's ability to establish connectivity:** As shown in Figure 8a, “E” stands for “the elders”, “W” stands for “the external world”, the dotted circles stand for connectivity scope. This principle starts with the elderly's own ability and focuses on strengthening and improving the physical and psychological capabilities of the elderly to help them expand their connectivity scope. It mainly includes the development of smart products and services to enhance and compensate for the elderly's weakened ability, exercise, and rehabilitation training equipment to help them recover and maintain their abilities to the level that they have not been weakened before.
- Reduce the difficulties and barriers from products and services aspects to establish connectivity:** As shown in Figure 8b, this principle starts from the smart home system itself which intends to provide a more friendly, intuitive, direct, and systematic control and operation method to reduce the difficulties and barriers for the use of relevant products and services, improve their usability and ease of use to put the elderly in the contactable range.
- Increase the opportunities of establishing connectivity:** After connectivity establishment, we can think about how to build more connection scenarios which are presented by “We1-WeN” in Figure 8c. This principle requires a deep understanding of the essential needs of the elderly, grasping the explicit needs, tapping the hidden needs to create more connectivity opportunities. For example, some elderly people in China always take care of their grandchildren after their retirement, so that the development of smart home can embed early childhood education and entertainment games to enhance intergenerational communication.

- **Improve the quality of the established connectivity:** On the basis of reducing the difficulty of establishing connectivity and creating more connectivity scenarios, then it comes to the optimization of connectivity quality, which is a conversion from quantity to quality, as shown in Figure 8d. It is not only the optimization of smart home functions but also the optimization of experience and content, using intelligent methods to help the elderly live more independently and safely and bring them a sense of wellbeing at home.

## 7. Conclusions

The core of the design and development of a smart home for older adults is to help them build connectivity both physically and psychologically to improve their quality of life and acquire an independent, safe, and happy elderly life. For the aging group, the “new elders” are completely different from our previous and conventional impression of the elderly. They love life, are willing to embrace fresh and new things and are inextricably linked to the Internet. The biggest problem for the elderly is that, with the decline of physical and social functions, their connectivity with the family, society, and the external world is not only degraded and separated in the physical aspect, but also psychologically. Therefore, the design and development of smart home products, services, and platforms for the elderly must not only focus on the physical needs but also need to help them establish psychological connectivity with the external environment and improve their comprehensive sense of wellbeing. This study analyzes the characteristics of Chinese “new elders” group, put forwards how smart home can help the elderly to establish connectivity both physically and psychologically, introduce Kano model analysis method to conduct empirical research to provide proof for the thirty smart home subsystems to help Chinese future elders build physical and psychological connectivity, proposes a basic smart home system architecture which realizes all-round wellbeing for the elderly and summarizes the principles of connectivity establishment for older adults in the smart home. The study explores the possibility of a smart home to build a comprehensive happiness home environment for the future elderly and provides plenty of innovative insights and suggestions for the development of the smart home industry and pension industry.

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**Conflicts of Interest:** We note that a shorter conference version of this paper appeared in the 16th International Conference on Intelligent Environments (IE2020) proceedings. Our initial conference paper did not include the content of empirical research. This manuscript extends and enriches all the content of the article and introduces the Kano model to conduct an additional attribute investigation on the thirty smart home subsystems which providing much more convincing evidence and rational statement to support our analysis and conclusion.

## Appendix A

The following is the main measurement and questionnaire we used. Each smart home subsystem item has been set three questions, the functional and dysfunctional questions for the kano survey and one more question about the importance of the relevant subsystem. For each functional form and dysfunctional form, there are five answers that can be selected: “I like it that way”, “It must be that way”, “I am neutral”, “I can live with it” and “I dislike it that way”. The importance of each subsystem is coded from “1 = not important at all” to “9 = Extremely Important”.

Home appliances system

- If the smart home has the home appliances system, how do you feel?
- If the smart home doesn’t have the home appliances system, how do you feel?

- Please score the importance of the above home appliance system.

#### Daily life service system

- If the smart home has the daily life service system, how do you feel?
- If the smart home doesn't have the daily life service system, how do you feel?
- Please score the importance of the above daily life service system.

#### Nursing system

- If the smart home has the nursing system, how do you feel?
- If the smart home doesn't have the nursing system, how do you feel?
- Please score the importance of the above nursing system.

#### Health detection system

- If the smart home has the health detection system, how do you feel?
- If the smart home doesn't have the health detection system, how do you feel?
- Please score the importance of the above health detection system.

#### Disease prevention system

- If the smart home has the disease prevention system, how do you feel?
- If the smart home doesn't have the disease prevention system, how do you feel?
- Please score the importance of the above disease prevention system.

#### Telemedicine system

- If the smart home has the telemedicine system, how do you feel?
- If the smart home doesn't have the telemedicine system, how do you feel?
- Please score the importance of the above telemedicine system.

#### Training rehabilitation system

- If the smart home has the training rehabilitation system, how do you feel?
- If the smart home doesn't have the training rehabilitation system, how do you feel?
- Please score the importance of the above training rehabilitation system.

#### Emergency response system

- If the smart home has the emergency response system, how do you feel?
- If the smart home doesn't have the emergency response system, how do you feel?
- Please score the importance of the above emergency response system.

#### Temperature and humidity control system

- If the smart home has the temperature and humidity control system, how do you feel?
- If the smart home doesn't have the temperature and humidity control system, how do you feel?
- Please score the importance of the above temperature and humidity control system.

#### Lighting control system

- If the smart home has the lighting control system, how do you feel?
- If the smart home doesn't have the lighting control system, how do you feel?
- Please score the importance of the above lighting control system.

#### Door and window control system

- If the smart home has the door and window control system, how do you feel?
- If the smart home doesn't have the door and window control system, how do you feel?
- Please score the importance of the above door and window control system.

#### Environment monitoring system

- If the smart home has the environment monitoring system, how do you feel?
- If the smart home doesn't have the environment monitoring system, how do you feel?
- Please score the importance of the above environment monitoring system.

#### Energy saving system

- If the smart home has the energy saving system, how do you feel?
- If the smart home doesn't have the energy saving system, how do you feel?
- Please score the importance of the above energy saving system.

#### Smart home theater

- If the smart home has the smart home theater, how do you feel?
- If the smart home doesn't have the smart home theater, how do you feel?
- Please score the importance of the above smart home theater.

#### Digital game system

- If the smart home has the digital game system, how do you feel?
- If the smart home doesn't have the digital game system, how do you feel?
- Please score the importance of the above digital game system.

#### Smart party system

- If the smart home has the smart party system, how do you feel?
- If the smart home doesn't have the smart party system, how do you feel?
- Please score the importance of the above smart party system.

#### Smart knowledge system

- If the smart home has the smart knowledge system, how do you feel?
- If the smart home doesn't have the smart knowledge system, how do you feel?
- Please score the importance of the above smart knowledge system.

#### Smart education system

- If the smart home has the smart education system, how do you feel?
- If the smart home doesn't have the smart education system, how do you feel?
- Please score the importance of the above smart education system.

#### The smart interest assistance system

- If the smart home has the smart interest assistance system, how do you feel?
- If the smart home doesn't have the smart interest assistance system, how do you feel?
- Please score the importance of the above smart interest assistance system.

#### Family connectivity

- If the smart home has the family connectivity system, how do you feel?
- If the smart home doesn't have the family connectivity system, how do you feel?



- Please score the importance of the above family connectivity system.

#### Friendship connectivity

- If the smart home has a friendship connectivity system, how do you feel?
- If the smart home doesn't have the friendship connectivity system, how do you feel?
- Please score the importance of the above friendship connectivity system.

#### Couple connectivity

- If the smart home has the couple connectivity system, how do you feel?
- If the smart home doesn't have the couple connectivity system, how do you feel?
- Please score the importance of the above couple connectivity system.

#### Pet connectivity

- If the smart home has the pet connectivity system, how do you feel?
- If the smart home doesn't have the pet connectivity system, how do you feel?
- Please score the importance of the above pet connectivity system.

#### Artificial intelligence connectivity

- If the smart home has an artificial intelligence connectivity system, how do you feel?
- If the smart home doesn't have an artificial intelligence connectivity system, how do you feel?
- Please score the importance of the above artificial intelligence connectivity system.

#### Grandchildren babysitting

- If the smart home has the grandchildren's babysitting system, how do you feel?
- If the smart home doesn't have the grandchildren's babysitting system, how do you feel?
- Please score the importance of the above grandchildren's babysitting system.

#### Peers supporting

- If the smart home has the peers supporting system, how do you feel?
- If the smart home doesn't have the peers supporting system, how do you feel?
- Please score the importance of the above peer supporting system.

#### Uncompleted wishes fulfillment

- If the smart home has the uncompleted wishes fulfillment system, how do you feel?
- If the smart home doesn't have the uncompleted wishes fulfillment system, how do you feel?
- Please score the importance of the above home appliance system.

#### Re-employment and society contribution

- If the smart home has the re-employment and society contribution system, how do you feel?
- If the smart home doesn't have the re-employment and society contribution system, how do you feel?
- Please score the importance of the above-uncompleted wishes fulfillment system.

#### Reality accomplishment

- If the smart home has the reality accomplishment system, how do you feel?
- If the smart home doesn't have the reality accomplishment system, how do you feel?
- Please score the importance of the above reality accomplishment system.

#### Virtual accomplishment

- If the smart home has the virtual accomplishment system, how do you feel?
- If the smart home doesn't have the virtual accomplishment system, how do you feel?
- Please score the importance of the above virtual accomplishment system.

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