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Reorganisation and Construction of an Age-Friendly Smart Recreational Home System: Based on Function–Capability Match Methodology

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Abstract: Elderly users are unable to adapt to the technological dividend brought by the internet of everything as soon as possible due to the deterioration in cognitive and perceptual functions, especially in the state of development of modern intelligent homes whose users' practical operational capabilities cannot be matched. This situation creates a digital divide in which older users also need helpmate intelligent home systems. Current research on innovative home systems often lacks a focus on the elderly and a matching mapping between smart homes and operational capabilities. Therefore, this study proposes a theoretical approach and model based on the matching between smart home functions and older users' abilities. This modelling path provides specific guidance for actual smart home design practices. This study outlines the methodology, theoretical derivation, and construction of the user capability gradient for matching functions and requirements of elderly users. Based on a theoretical model, experimental data, and threshold law in practical application, the age-appropriate intelligent home control system is developed independently, and the integrated development of hardware and software cloud synergy is realised for the user pain points of elderly users to make up for the gap at this research level.

Keywords: framing; human–computer interaction; human factors; system(s) design; age-friendly design

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Citation: Zhou, C.; Huang, T.; Luo, X.; Kaner, J. Reorganisation and Construction of an Age-Friendly Smart Recreational Home System: Based on Function–Capability Match Methodology. *Appl. Sci.* **2023**, *13*, 9783. https://doi.org/10.3390/app13179783

Academic Editor: Paulo Santos

Received: 26 June 2023
Revised: 19 August 2023
Accepted: 26 August 2023
Published: 29 August 2023

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1. Introduction

The development of artificial intelligence from the initial intelligent computer has now been updated and crossed over to the home industry [1,2]. The idea of the smart home has moved into the realm of the home, with scene migration, multi-channel experiences, and other intelligent linkages emerging [3,4]. Initially, the innovative home concept was simplified by adding intelligent products. Later, with the introduction of the concept of the internet of everything, the intelligent home ecosystem was gradually built, with various home living scenarios being involved [5–8]. The development of smart homes has, to a certain extent, brought convenience to the elderly or people with special needs. For example, introducing intelligent home systems under the COVID-19 pandemic can facilitate caretakers to take care of particular groups [9–11]. The development of smart homes has likewise revealed many problems, privacy issues, operational issues, etc., that need to be resolved [12,13]. Globally the ageing population is increasing, and older consumers are changing their attitudes while wanting a higher quality of life [14]. As a result, the wellness industry is also gradually developing, with age-friendly intelligent home systems and products attracting attention. For example, elderly users often have poor sleep quality and intelligent mattresses can be adjusted according to individual differences and can provide real-time feedback on sleep data for reference [15–17]. However, in the actual effect

feedback, elderly users often have cognitive biases in using innovative home products and systems due to cognitive differences.

On the contrary, it is easy to stimulate negative emotions among elderly users, which brings more difficulties and obstacles. In designing and applying innovative wellness products, voice control is most commonly used [18]. However, realistic feedback exists about poor dialect recognition and misuse behaviour due to poor language representation. Therefore, the degree to which the product's functionality is developed to match the user's abilities is critical. Risks and challenges must be envisaged in the early stages of product development [19–21]. Actual user satisfaction feedback at the beginning of product testing is also crucial [22,23]. Product interactions take the product interface as an example: the age-appropriate interface design needs to confirm the final interface elements, such as font, spacing, and layout, through the usage habits and physiological data of elderly users [24,25].

2. From Competence Studies to Functional Pathways for Age-Friendly Furniture

User competence is concretely reflected in the range of hands-on user performance, i.e., the threshold of user competence. User capabilities are inextricably linked to factors such as age and experience. From the earliest days of human physiology, research into human capabilities gradually moved to the industrial production level. Ergonomics is widely used in all industries, and with the user at the centre of the process, it is possible, on the one hand, to pinpoint and, on the other hand, to improve the user's perception of the product's use and to extend its life cycle.

The functional development of age-friendly furniture needs to be based on the actual capabilities of the elderly user [26,27]. The rapid development of the market will lead to further subdivision of furniture design to match the abilities of elderly users, for example, by age group, behavioural ability, place of use, etc. According to market research, intelligent design for elderly furniture products is a hot design trend. Intelligent design products are in their infancy in the senior furniture market, and the existing products are mainly focused on developing and applying intelligent functions. With the development and application of various sensing and wireless technologies, intelligent senior furniture will gradually change from the traditional form of technical interaction to a behaviour-centred lifestyle, focusing on the complex interaction of movement and social interaction to create a comfortable environment for the elderly.

In 1943, Abraham H. Maslow and others put forward the capability–demand theory, which also follows the information processing model in classifying the capabilities of users [28]. The relationship between the product and the user is a two-way one, where the user's actual capabilities determine the requirements for the product itself, and the product's capabilities are adapted to the user's needs [29,30]. In such secondary iterations, information often needs to be recovered. Users often choose to change their actual needs due to the lack of functionality of the product, which results in the embarrassing situation of lost pain points and single-product functionality in the current market [31–36]. In the theoretical model of capability–demand, the sub-variables associated with it can be divided into four tiers: (1) user, (2) product function, (3) interaction environment, and (4) the most noteworthy tier of interaction links remains in the user and product function. The margin of fit between the user's actual capabilities and the product's functionality guides the final product output.

The overall reflex system, in which the human being is stimulated, and the perceptual, cognitive and reactive systems process the relevant information in correspondence to make an action, is known as the human information processing model (Figure 1). The closed-loop process consists of seven steps: (1) The information input stage, where external stimuli are completed by perceiving the product information; this is the perception stage. (2) The central nervous action of the brain reacts to and instructs the relevant information and has a memory effect. (3) The brain makes preliminary calculations for the relevant processes. (4) The brain calculates further goals to set the next activity goal. (5) The brain

gives instructions to the relevant parts of the body, and the activity proceeds. (6) The body parts disassemble and distribute the action according to the brain's instructions to perform the information output: where (2)–(6) are cognitive stages. (7) The body parts perform specific operations to complete the assigned tasks, the operation execution stage. The information processing model is mainly used to understand the information interaction process between elderly users and home products to discover the operational difficulties and carry out assisted improvement design to help elderly users complete the information interaction process.

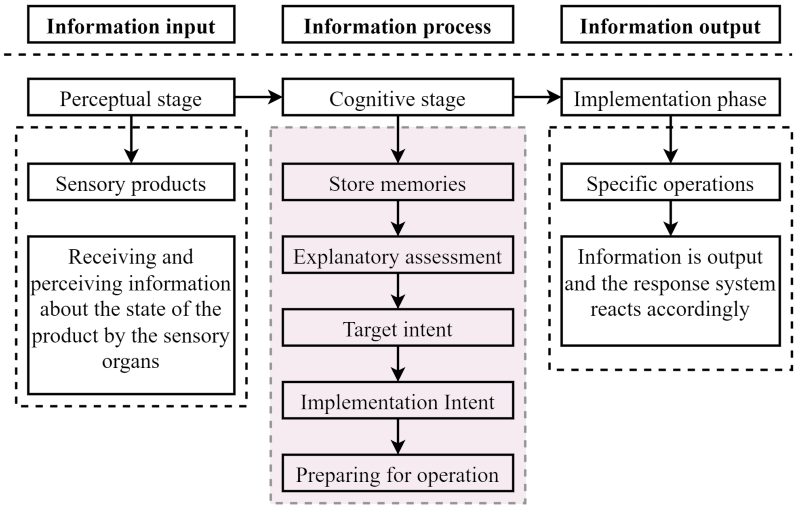


Figure 1. Human information processing models.

Information input, as the central part of the first stage, is the first step in the interaction behaviour of people and products, etc. People perceive external information primarily through their sensory organs, followed by the brain's reaction and judgement. The human information processing process is divided into three stages: information input, information processing, and information output. The three-stage processing model of memory information can be divided into three categories: sensory, short term, and long term (as shown in Figure 2).

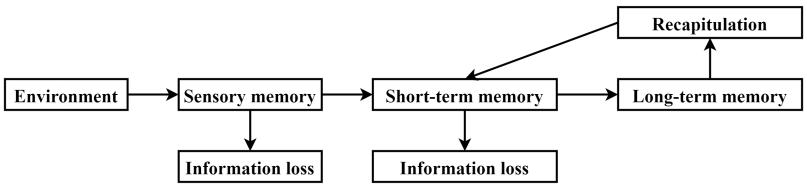


Figure 2. Three-level processing model of memory information.

The information-processing theory divides the processing and memory of information into three levels, with the perceptual organs receiving external stimuli and the brain up to the central nerve making relevant responses. The brain is a considerable information transit and processing centre. The brain never stops processing and feeding back information. The brain divides the acquisition of information to the release of final orders into three levels, and the whole information processing operation process is interlocked. As the centre of information perception, collection, and processing, the brain divides information according to its importance, with sensory and short-term memory eventually leading to loss of information. Therefore, in product interaction and development, temporary storage of sensory and short-term memory is a need of concern (as shown in Figure 3). Information processing is divided into perception (sensory memory and perception), cognition

(attention, long- and short-term memory, reasoning, and response selection), and execution (response execution). The significant function of age-appropriate products is to fill the gap in information processing for elderly users, assist them in their daily lives, and adapt to their practical needs as their physiological mechanisms have declined. Their perception and pre-processing of information need to be recovered.

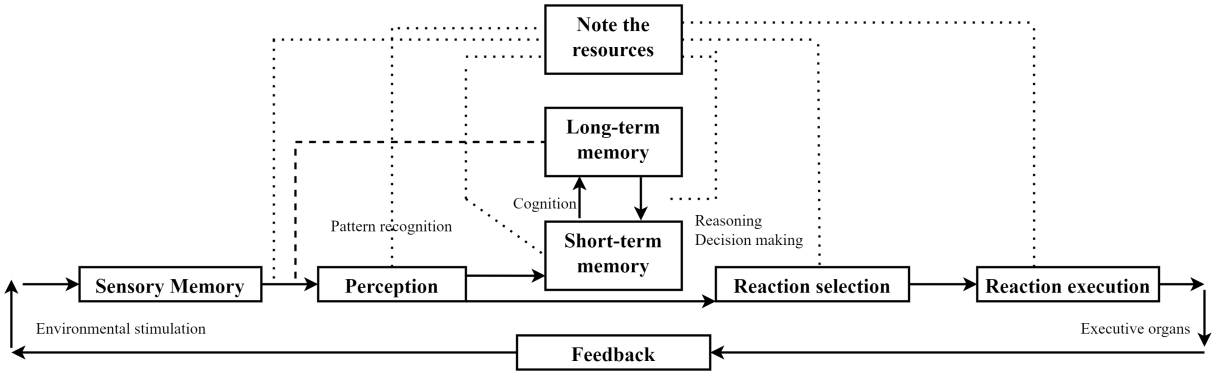


Figure 3. Information processing simulation diagram.

3. Building Blocks: Home Product Functionality and User Capability

Product functionality refers to the range of capabilities a product can provide and the range of capabilities required for the user to operate it. The function refers to the basic functionality of the product. The 'capabilities' in the user's life capabilities refers to the user's capabilities in practice. The function refers to the product, and the ability refers to the user, so the process of matching product and user can be reduced to the matching process of function and ability. There is a mapping relationship between product function X and user life capability Y (as shown in Figure 4).

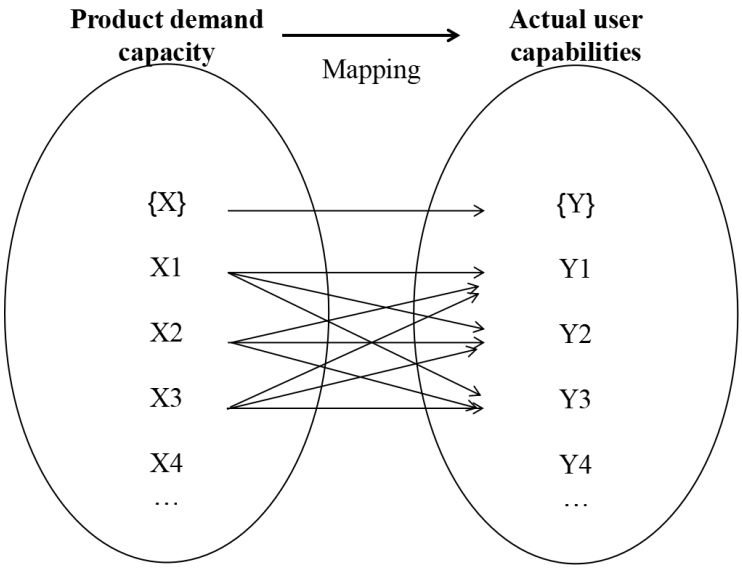


Figure 4. Mapping product functionality to user life capabilities.

Home product features (HPF) and user actual capability (UC) are the two variables used as thresholds for comparison in this study.

The traditional design system $C = (ED, OD)$, which consists of the event domain and object domain, is reconstructed into a complex system consisting of three parts, namely, the event domain, object domain, and active domain, with a mapping relationship between them, as shown in Figure 5.

$$C' = (ED, OD, AD) \tag{1}$$

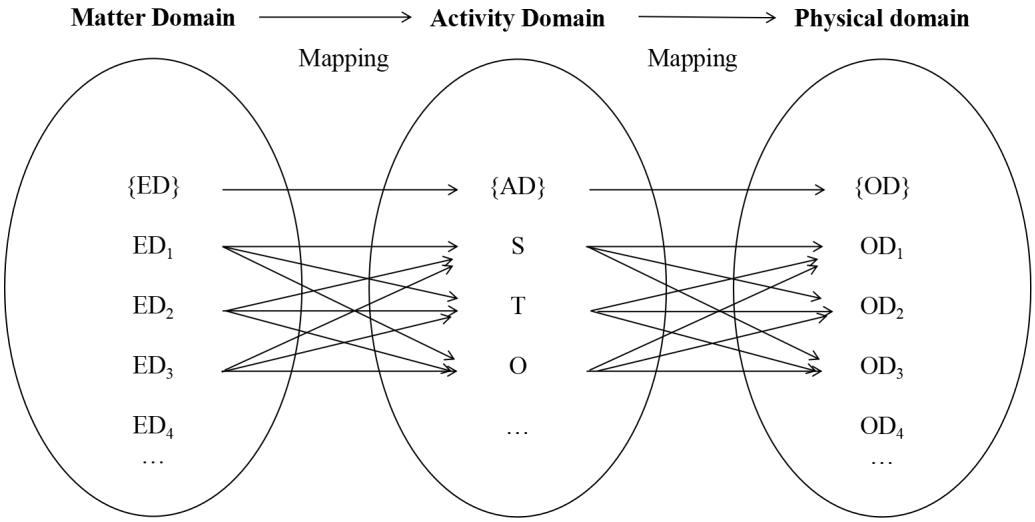


Figure 5. Mapping system for matter, object, and activity domains.

For the event domain, the main elements of the event domain are divided into user lifestyle (L, lifestyle), user environment (E, environment), and user group (U, user), so the event domain of the elderly user's life can be expressed as

$$ED = fED(L, E, U) \tag{2}$$

fED is a model for expressing the elements of age-friendly furniture design in the matter domain.

For the matter domain, the subject matter elements that make up the matter domain are products (P, product):

$$OD = fOD(P) \tag{3}$$

fOD is a model representing the elements of age-friendly furniture design in the object domain.

For the activity domain, it can be split into the activity subject (S, subject), the activity tool (T, tool), and the interaction object (O, object), so the expression for the activity domain can be written as

$$AD = fAD(S, T, O) \tag{4}$$

fAD is the expression model for the elements of age-friendly furniture design in the activity domain.

The mapping of home product functions and user life capabilities is developed explicitly in the matter domain, object domain, and activity domain mapping system. The use of home products requires users to have specific equivalent capabilities. The mismatch between home product functions and user life capabilities will bring about a waste of resources and capabilities, so it is necessary to dismantle the home product functions and code them to study the user life capabilities that match the functions of different categories of home products. The ability to match the functions of different categories of household products is, therefore, investigated by dismantling them and coding their functions.

4. Model Building: FCM—Function–Capability Matching

4.1. FCM: Function–Capability Matching Theory

4.1.1. Methodology

Starting from the primary interaction link of information reception, we find out the possible difficulties of elderly users in information reception and use the ability–needs matching method to research this, thus proposing the FCM (function–capability match) household product function–user life ability matching method. (1) Target layer establishment: The target layer belongs to the designer's idealised category. (2) Transformation of the implementation layer: The suitability of user needs and product functions is observed in the actual product use. The actual execution ability of the elderly user and the product's function is docked, and the bridge between the demand ability (the actual ability of the user) and the actual ability (the additional function of the product) is completed in both directions.

The specific principle of the FCM home product function–user life ability matching method is that the user's interaction process experience can fluctuate within the ability matching range and the ability margin. The product's primary functions are added to match the user's ability to meet different users' needs for fresh and applicable products (as shown in Figure 6). The designer can then flexibly match the corresponding area with different target users' and producers' needs, avoiding the range of insufficient ability matching and, thus, achieving a balanced and unified paradigm value of function–ability. When people interact with the product, the actual ability of the user is no longer based on the hierarchy but on individual differences. The data are collected and aggregated to give feedback to the designer, which is a guideline for the additional functionality of the product.

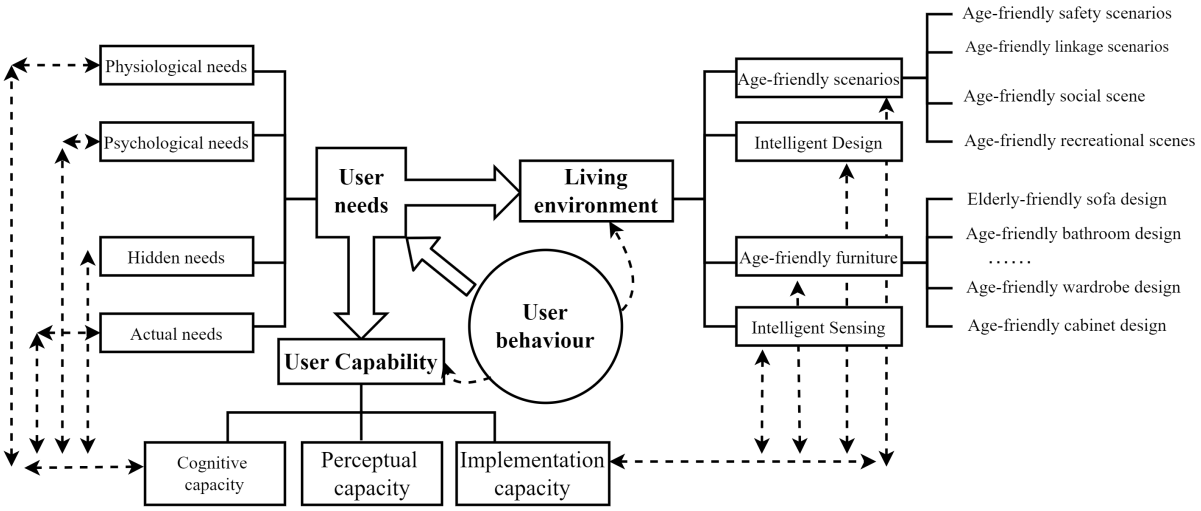


Figure 6. Principle of FCM function–capability matching method.

The user ability ladder is constructed to study the correlation between user ability and home product functions. The user capability study is divided into four modules to comprehensively evaluate the user's capability range, construct a user capability ladder, and comprehensively derive a user behaviour model: user home behaviour clustering and analysis, user perceived capability assessment, user cognitive capability assessment, and user execution capability assessment.

The model reflects the matching relationship between home product features and user life capabilities in internet interaction, categorising user life capabilities into perceptual, cognitive, and executive capabilities. Home product functionality is divided into home product features (hardware) and interaction form features (software). Users' use of home products requires actual user capabilities, which also regulate the scope of basic home product features. The elderly user group is distinguished from the young group by its phys-

iological and psychological influences, weakened abilities, and susceptibility to operational processes. Therefore, it is necessary to coordinate the dynamic influence of all aspects of interaction to achieve a match between the construction of the user ability gradient and the product functionality, which is expressed in the following formula.

$$FCM = IE(HPF + UC) \quad (5)$$

where *FCM* is the function–capability match, *IE* is the internet environment, *HPF* is home product features, and *UC* is user capabilities. The aim is to build an intelligent home system based on the adaptability between home product features and the living ability of elderly users in the internet environment to improve the quality of the daily life of elderly users and avoid obstacles.

4.1.2. Theoretical Derivation: The Function–Competence Matching Process

The primary functions of household products are clearly defined. For example, sofas sit and lie down, giving users a place to rest briefly. With the development of productivity, users' demand for products is no longer only satisfied with the traditional essential functions, and the upgrading of products continues beyond the adjustment of the appearance of the colour palette. The comparison of product sales often tends to favour iterations of product added value. It is, therefore, vital to find a dynamic balance between functionality and capability in production applications rather than just overlaying ancillary functionality, making it difficult for users to use and leading to higher development costs and wasted resources. By establishing a decision point for function–capability matching, designers can facilitate product development and project creation and have a more convenient decision space and decision-making environment.

The FCM home product function–user life capability matching method can effectively assess the match between the product function level and the user's perception, cognition, and execution capability level in the product design process to seek the actual demand decision point and play a guiding role in the design process. Overall, the FCM home product function–user life capability matching method mainly elaborates on four modules, including the internet interaction environment module, the product function iteration module, the life demand capability acquisition module, and the user capability gradient construction module, in which the product function includes the user's demand for the environment and the user's demand for the furniture function. The key is that the designer can match the diverse needs of the manufacturer and the user according to the user's gradient ability data and adapt to the changing interaction environment. The relationship and process of matching user capability gradients to product requirement levels, and the advantages of the FCM home product function–user life capability matching approach will be further specified in the following sections.

4.2. User Capability Ladder Construction

The psychological emotions that arise when users interact with the product are what designers need to judge. Whether the user's ability matches the product's function and whether the user's operational performance is linearly related to the product's adaptation range. The M-value is the turning point between lack and matching, and the S-value is the turning point between matching and surplus, which is the critical turning point used to study the ability threshold of different gradients of users, as shown in Figure 7.

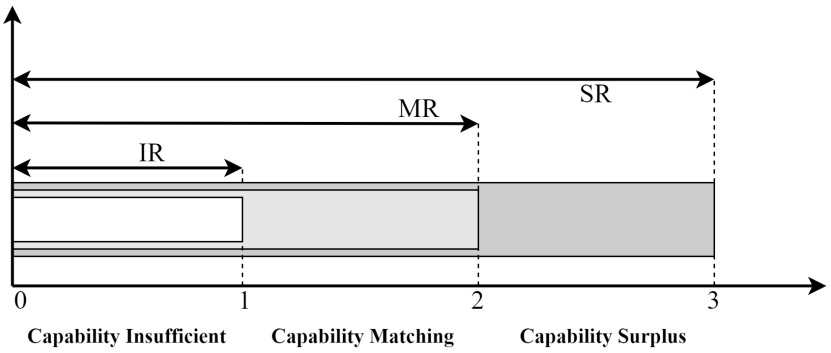


Figure 7. User capability gradient construction threshold range.

(1) SR/Capability Surplus Range

At this stage, the user's ability to operate is greater than the actual function of the product. When the user's ability to operate is within this threshold, the use of the product is simple and clear to the user, and the product development costs are low. Nevertheless, at the same time, the low level of difficulty can lead to monotony and fatigue, and the product can only be used as an essential everyday product.

(2) MR/Capability Matching Range

The range of ability matching is between the M-value and S-value, i.e., between MR and SR. The user's actual operating ability and the product's function are balanced in this range. This threshold range of the user using the product is relaxed and exciting, which can keep the user's desire to explore the product. These products usually have additional functions, which can better and more conveniently assist the user in daily life. This range is the best area for companies to consider regarding R&D and designers, and this range allows for better user benefits and additional product value.

(3) IR/Capability Insufficient Range

The under-ability range is the IR zone, where the user's actual ability is much lower than the product's capabilities. Users in this zone often feel frustrated and unable to operate the product, thus leading to negative emotions such as frustration and discouragement.

4.3. Theoretical and Methodological Multi-Dimensional Advantages

The FCM home product functionality–user life ability matching method can help companies and designers determine the target consumers' actual ability in the product development process and select additional functions for the product. According to the FCM home product functionality–user life ability matching model, the best choice for R&D and designers is to design within the ability matching range, which can match the actual needs of users and maximise the added value of the product. This method applies to the designer, production, and user levels.

4.3.1. Designer Level

By studying specific criteria, traditional capability–demand relationships often refer to collecting data that lead to relevant shaving ranges. The designer generally gives the user one interval that contains the limit values used for what is acceptable, and thus, subjectivity needs to work better in this regard.

The real-life decisions taken by designers are influenced by various factors, not limited to the needs of a particular party. Therefore, they must consider various factors, including the manufacturer, user, strategic selling point, frequency of use, technological means, production costs, and social impact. In contrast to the traditional so-called specific matching relationships, the FCM approach provides the designer with a more prosperous, many-to-many gradient reference range based on the median value of all relevant factors in the relevant selection plan. The number of solutions can be increased geometrically.

4.3.2. Production Level

This is often based on a study of existing user capabilities, which leads directly to the so-called ideal design criteria. A single user-driven approach tends to waste virtual and even natural resources, resulting in overproduction in the factory at great expense but with little success.

At the same time, design solutions are often limited to more than a single design criterion due to actual production costs and technical constraints. Therefore, the FCM home product function–user life ability matching approach considers various factors and conditions so that while meeting the basic needs of the user, the different needs of the user are divided into a hierarchy of levels to give targeted advice. It allows for flexibility in the choice of a range of crucial functions that are frequently used by users and core functions that are designed to meet the needs of users at a strategic level while providing more options in the design criteria when challenging experiences or non-core product functions are required, and helping manufacturers to compete with similar products through the choice of a range of adaptations.

4.3.3. User Level

The user experience is related to the relationship between the user's capabilities and the requirements' capabilities. When there is insufficient matching, the perception of subtasks at each level of completion increases not only the perceived difficulty and execution but also the burden and frustration of the user, to the extent that a large gap between the functional requirements and the user's capabilities will cause the product to fail in its operation. However, reducing the user's need for the product's functionality will result in repetitive and straightforward operations that bring the user a sense of boredom. In contrast, a sufficient matching margin will result in a discounted or even limited functionality compared to other competing products. The FCM home product function–user life ability matching method allows designers to provide users with more diverse design solutions to meet their individual needs by comparing and measuring user needs and function supply based on user ability.

5. Practical Verification: Smart Wellness Home System Pre-Architecture Design

The smart home is a residential platform that integrates embedded technology, sensor technology, network communication technology, automatic control technology, and home facilities to accomplish intelligent control of home life, making it more efficient and comfortable. Infrared, Bluetooth, ZigBee (Purple Bee protocol), radio frequency (RF), Wi-Fi (wireless communication technology), and other short-range communication technologies, which can easily transmit the information collected by sensors to the IoT gateway, compared to wired communication, provide the conditions for the realisation of intelligent homes. In traditional IoT intelligent home control, APP (application) control is mainly used, but it is limited by problems such as long R&D cycles and expensive R&D costs. Therefore, this study's intelligent home system, designed independently, mainly uses Wi-Fi to connect the smart gateway to the mobile phone and realises indoor intelligent control through the mobile phone applet designed and developed separately. Users can complete the click operation directly on the mobile phone, and the applet's background, combined with the communication module, transmits the data to the central controller, which sends commands to the nodes, thus realising the control of intelligent terminals such as furniture or home appliances. The central controller refreshes the data at regular intervals by sending data requests to the sensor nodes, thus refreshing the sensor data. The architecture of the home intelligence system consists of three parts: the application interface layer, the LAN communication layer, and the intelligent device terminal layer. In general, the application interface layer is mainly open to users and includes the business logic layer architecture and the database; the LAN communication layer consists of the Wi-Fi-based device LAN, the home intelligent device master controller; the smart device terminal layer contains

the control communication module, the sensor element or module, the control element or module, and the power supply.

The home intelligence system built by this study includes an application interface layer, a local area network communication layer, and an intelligent device terminal layer (as shown in Figure 8). In the application interface layer, the home intelligence system is open to the user with a home control system applet that meets the operating ability of the elderly user, and the user can enter commands by clicking on the applet. The data from the user's intelligent devices are eventually uploaded to the cloud platform via the home centre and entered into the cloud database, where the data are stored for backup. The user can also access the database of the cloud platform by operating the application interface layer and using the applet as an interface to obtain data information such as the length and duration of use of the intelligent terminal device (as shown in Figure 9).

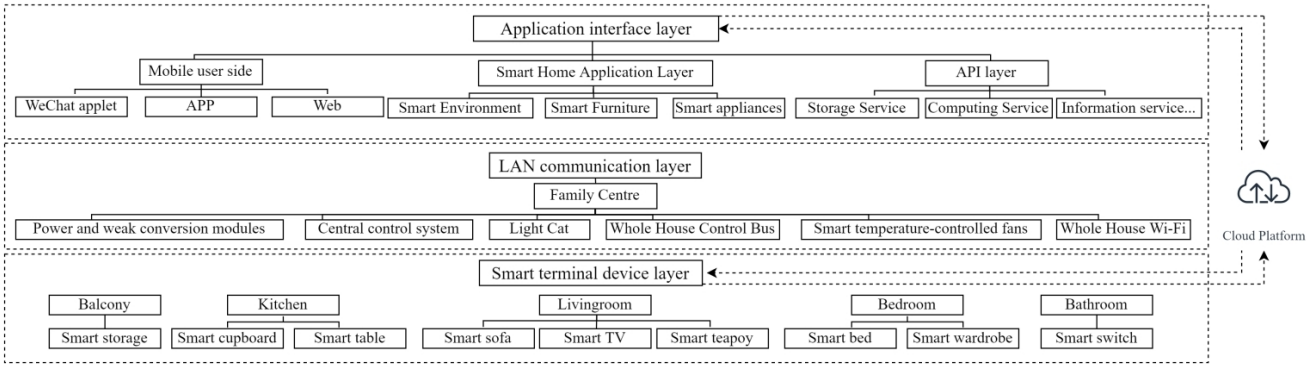


Figure 8. Architecture design for home intelligence systems.

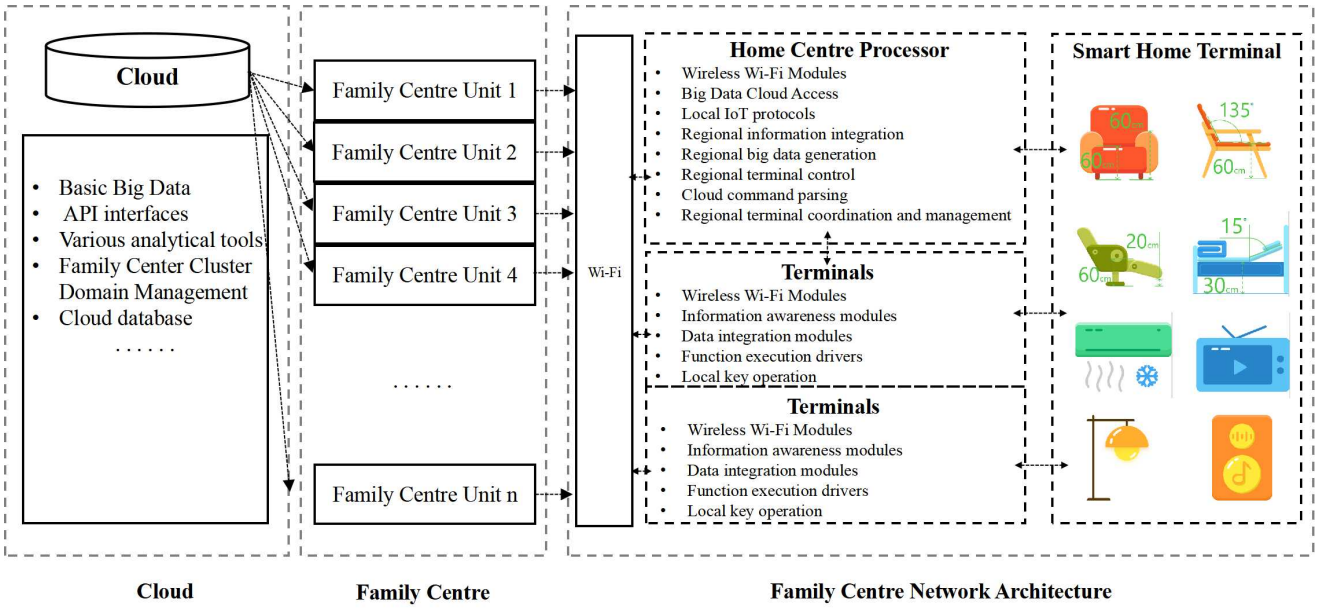


Figure 9. Detailed explanation of data transmission in smart home system.

6. Discussion

The innovative home system has an application interface layer, a local area network communication layer, and an intelligent terminal device layer, and it is built on an independent cloud platform and a Wi-Fi wireless network. Furthermore, when combined with the experimental results of independent research and development, the user can choose to operate the control program's corresponding interface to adjust the home environment's functional requirements, household goods switch, furniture height, tilt, temperature,

and other functions. The control program will also record the elderly users' operation results, while providing real-time data collection and instant feedback. This provides database support for subsequent intelligent home product development. Developing healthy and comfortable, age-friendly home environments and furniture with the help of scientific research and emerging technologies has become a current and future research hot spot and industrial trend. This study builds an intelligent home control system and evaluation indicators based on the study of the living environment and furniture needs of elderly users, intending to improve the comfort of age-friendly homes, improve the health management of elderly users, and improve the quality of life of elderly users, providing reference paths for the creation of modern elderly living environments and subsequent furniture development with age-friendly home systems and furniture products, and providing vital guidance for the sustainable development and iteration of age-friendly homes.

Distinguishing the traditional man–machine approach to studying the size of elderly furniture or elderly behavioural styles, this study innovatively constructs a theoretical model of age-appropriate home function–user living ability to form a mapping relationship between elderly home function and user ability. The method divides user capabilities into differentiated gradient ranges of capability deficiency, capability matching, and capability surplus ranges. It focuses on the theoretical model, matching process, and gradient construction of the matching function and needs of elderly users. The model can be divided into four modules, including the module of internet interaction environment, the module of life ability acquisition, the module of product function iteration, and the module of user ability construction gradient, and the four modules constantly interact with each other and iterate in order to achieve the goals of data collection, sustainable analysis, and iterative upgrading.

7. Conclusions

This study starts from the fundamental interaction of information reception, identifies the difficulties that may exist in the information reception of elderly users, introduces the ability–needs matching method, and establishes a systematic and complete ability–needs matching method for FCM. The study of elderly users' life abilities is transformed into the study of three types of abilities: perception, cognition, and execution. The needs of elderly users are profoundly analysed, the existing home product functions are quantified in a gradient to match them, and finally, the relevant inner matching demand pattern is derived, which completes the auxiliary elderly users' behaviour and establishes iterative data integration.

(1) The FCM home product function–life ability matching method can be understood as a matching relationship between the user ability gradient and product demand level.
(2) The FCM home product function–living ability matching method links user needs (physiological needs, psychological needs, actual needs, hidden needs), user abilities (cognitive ability, perceptual ability, execution ability), and studies user behaviour in the user living environment, to design an intelligent home system for the user that meets the user's needs.
(3) After analysis, the ability range of senior living is divided into three adaptation ranges: ability surplus range (SR), ability matching range (MR), and ability lacking range (IR).
(4) The intelligent functions of age-friendly furniture can be split into four design elements: intelligent recognition function, intelligent adjustment function, intelligent monitoring function, and intelligent prompting function under the theoretical guidance of the FCM home product function–life ability matching model.
(5) The advantages of the FCM approach are highlighted at the designer, production, and user levels. The FCM model focuses on the connection between the user's environment, the user's demand for home product functions, and the user's ability to live.

Author Contributions: C.Z. contributed to data curation, funding acquisition, and writing—review and editing. T.H. contributed to data curation, methodology, visualization, and writing—original draft. X.L. contributed to visualization. J.K. contributed to writing—review and editing. All authors have read and agreed to the published version of the manuscript.

Funding: Part of this work was supported by the National Key Research and Development Program (2017YFD0601104), and part of it was supported by the 2020 Jiangsu Postgraduate "International Smart Health Furniture Design and Engineering" project, and 2022 Jiangsu Province Ecological Health Home Furnishing Industry-University-Research International Cooperation Joint Support for laboratory projects. Part of this work was also sponsored by Qing Lan Project.

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study. Written informed consent has been obtained from the patients to publish this paper. The study was conducted in accordance with the Declaration of Helsinki, and the protocol was approved by the Ethics Committee of Nanjing Forestry University.

Data Availability Statement: Not applicable.

Acknowledgments: Thanks for the research technical and ErgoLAB Man-Machine-Environment Testing Cloud Platform (ErgoLAB v3.0) related scientific research equipment support of the Kingfar project team.

Conflicts of Interest: The authors declare no conflict of interest.

Abbreviations

The following abbreviations are used in this manuscript:

IoT Internet of Things

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