IEEE Access
Multidisciplinary : Rapid Review : Open Access Journal

Received 19 February 2024, accepted 28 March 2024, date of publication 1 April 2024, date of current version 10 April 2024.

Digital Object Identifier 10.1109/ACCESS.2024.3383925

RESEARCH ARTICLE

Older Users Acceptance of Smart Products: An Extension of the Technology Acceptance Model

HUI ZENG[1], **JINWEI ZHU**[2], **HANXI LIN**[3], **AND JUNMING CHEN**[4]
[1]School of Design, Jiangnan University, Wuxi 214122, China
[2]School of Business, Jiangnan University, Wuxi 214122, China
[3]School of Art and Design, Dalian Polytechnic University, Dalian 116034, China
[4]Faculty of Humanities and Arts, Macau University of Science and Technology, Taipa 999078, China

Corresponding author: Jinwei Zhu (jinweizhu@jiangnan.edu.cn)

This work was supported in part by the National Natural Science Foundation of China under Grant 72371118, in part by the Key Projects of Scientific Research in Universities of Anhui Province under Grant 2023AH050228, and in part by Anhui University of Finance and Economics School-Level Teaching Research Major Project under Grant ACJY2022010ZD.

ABSTRACT In response to the challenge of accurately assessing age-friendly design requirements during the improvement phase of smart products, a novel evaluation model is proposed. This model is grounded in the technology acceptance model and considers the interplay between user weights and requirements. The aim is to establish precise product indicators and development strategies, thereby maximizing user satisfaction and market competitiveness. Initially, design evaluation indicators are derived from the technology acceptance model. Subsequently, the TextRank algorithm and grounded theory are employed to determine the initial weights of these indicators. The DEMATEL method is utilized to analyze the weight of influence relationships between indicators, while the Kano model determines importance coefficients for adjusting weights. Through normalization, final weights are assigned, and the TOPSIS method implements sorting and significance analysis of age-friendly design requirements. Five age-friendly smartphone samples serve as case studies to evaluate and analyze the five age-friendly design requirement indicators. Method comparison and advantage/disadvantage sorting analyses are conducted to validate the effectiveness and feasibility of the proposed approach.

INDEX TERMS Age-friendly design, evaluation index system, smart products, technology acceptance model, TOPSIS.

I. INTRODUCTION

In the era of intelligent connection of all things, information technology is increasingly becoming the core pillar and service channel for the care of the elderly life, and the artificial intelligence-based lifestyle will gradually evolve into a new type of situation in the life of the elderly group [1]. Smart products, as a kind of key technical equipment to provide assistance to the elderly life, along with the accelerated pace of scientific and technological progress, so that its original nature of a simple tool has become feature-rich and complex operation [2]. However, due to the decline of physiological functions, the elderly population has a low degree of adaptation to digital technology, and even reflects imprecision, unnaturalness and discomfort when interacting with it. In view of the huge digital gap between the elderly and smart products, how to accurately control the degree of intelligence, effectively assess customer needs in product planning, and promote the mutual adaptation of scientific and technological innovations to the needs of the elderly has become a core topic of widespread concern in society [3]. At this stage, the use and popularity of needs assessment in the age-friendly design of smart products is relatively limited, and the study will further explore its influencing factors and internal mechanisms based on technology acceptance theory.

The associate editor coordinating the review of this manuscript and approving it for publication was Alessandro Floris.

Needs assessment, as a key design aspect of smart product development, has a decisive impact on the effectiveness of subsequent product technology guideline development and the quality of decision making for age-friendly design solutions [4]. How to focus on the age-friendly design requirements with high user satisfaction in the product improvement phase, and mine the core requirements that are highly sensitive to the age-friendly value of the product, is the key link to improve the feasibility and effectiveness of the product improvement design solution [5]. Regarding the problem of analyzing the demand indexes for age-friendly of products, the research mainly focuses on two aspects. (1) Requirements acquisition: Translating users' design expectations for smart products into canonical expressions of specific requirements [6]. (2) Requirements importance assessment: An assessment method is used to identify the satisfaction of requirements, and the prioritization of requirements is formed based on the results [7]. Although the aforementioned work can initially assess the core design requirements to ensure the use value of smart products, it involves a large amount of information with different dimensions, evaluation scales and expressions, lacks scientific treatment of customer demand categorization, and ignores the influence relationship between customer demand indicators, and how to integrate this information in evaluation decision-making is still an important challenge [8].

This study attempts to bridge the above research gaps with the following main objectives:

•To construct an evaluation index system oriented to the age-friendly design requirements of smart products, to improve the accuracy of the design evaluation and preference results, and to provide a feasible way of thinking for designers to preference age-friendly design solutions for products.

•Explore how to effectively translate from customer needs research to design solution validation, avoiding the blindness and susceptibility to loss of innovation due to the inability to weigh and choose between various factors in the design process.

•It is pointed out that the method of evaluating the age-friendly design requirements of smart products based on the technology acceptance model comprehensively considers the characteristic problem in multi-attribute evaluation and preference, and maximally optimizes the problem of design requirement decomposition and weight allocation.

This study takes the technology acceptance model as the main theoretical basis and research foundation, and takes perceived usefulness and perceived ease of use as the antecedent variables, and tries to construct an extended technology acceptance model to enhance the explanatory degree of the model on acceptance behavior. Considering the effectiveness of TextRank in extracting information keywords [9], the rationality of the Grounded theory in collecting and analyzing information systematically for the problem, discovering, developing and testing the theory from the information material [10], the systematicity of the DEMATEL (Decision-making Trial and Evaluation Laboratory) in identifying the influence relationship between the complex demand indicators [11], and the Kano model by establishing a functional relationship between the demand for smart products and the satisfaction of elderly customers, and thus the accuracy of adjusting the importance of customer needs [12], the study combines the above methods, calculates the relative closeness of the evaluation object to the optimal solution according to the TOPSIS (Technique for Order Preference by Similarity to an Ideal Solution) evaluation, and prioritizes the customer's needs [13], in order to help decision makers accurately identify the key requirements, reduce uncertainty, and formulate a reasonable design decision for age-friendly smart products.

This study is structured as follows. Section II presents a brief literature review on product design requirements and technology acceptance model approaches. Next, Section III describes the research design methodology, which integrates 4 methods, TextRank Algorithm - Grounded Theory - DEMATEL - Kano Model, and describes the evaluation system composition, sample selection and data collection. In Section IV, the application of the method is illustrated through an empirical analysis and discussion of a smartphone case. Subsequently, Section V validates the feasibility and effectiveness of the method. Section VI summarizes the study and presents future research.

II. RELATED RESEARCHES

A. SMART PRODUCT DESIGN REQUIREMENTS

The problem of assessing the age-friendly design needs indicators of smart products in the design conceptualization stage is mainly studied around two aspects.

Requirements analysis study. It consists mainly of two aspects: requirements acquisition and requirements importance assessment. Requirements acquisition, specifically referring to the translation of user design expectations for smart products into a canonical expression of specific requirements. For example, Muslim et al. [14] proposed the use of Web service recommender systems to analyze user experience data of available items/smart products to obtain user requirements. Wang et al. [15] refined users' perceptual needs based on the three dimensions of smart products, user perception, and behavioral prediction to provide a guiding path for improving the efficiency of product design. requirements importance assessment, specifically referring to the use of assessment methods to identify the satisfaction of needs and to form a prioritization of needs based on the results. For example, Liu and Wang [16] utilized the Kano model to classify the demand indicators into overall one-dimensional quality, charismatic quality, and necessary quality, which were used to obtain the service function and social demand of age-friendly products from elderly users. For the social and emotional elements that may reduce users' sustainable requirements during the development of age-friendly products. Liang et al. [17] proposed to assess the importance of requirements through a qualitative design approach. Zhang et al. [18] proposed a preference-based design model for age-friendly product to analyze the significant value of assisting smart product acceptance in uncertain design environments in three phases: definition, conceptualization and evaluation. The above work has an effective evaluation capability in determining the design needs for the value of age-friendly product development, however, there are certain limitations, such as subjectivity in the expert assessment process, which may lead to inconsistency issues in the results.

Demand transformation solution study. Lawry et al. [19] investigated the impact of changes in requirements on the optimization results of requirements design for two categories of users, older and younger, in conjunction with an empirical survey in familiarity analysis and validated it through coding. Li et al. [20] proposed a research method based on QFD (Quality function deployment) and Kano model for optimizing the design of user experience of smart products for the elderly to improve the overall satisfaction of users with smart products by identifying their potential requirements. When faced with the problem of not being able to determine the requirements evaluation environment, Efe et al. [21] proposed the use of IT2F (Interval Type-2 Fuzzy) improved fuzzy QFD method to analyze the link between customer needs and design requirements as a way of determining the requirements importance. Despite the validity of the above mentioned models in terms of subjectivity in demand extraction and fuzziness in evaluation, they show a clear neglect in terms of interactions correlations between demands. For this reason, Jose et al. [22] built an impact correlation matrix between digital product assessment indicators based on DEMATEL to make decisions on digital product parameters in different countries. Bhanot et al. [23] quantitatively analyzed the product evaluation metrics through DEMATEL and established a demand influence correlation diagram to represent the influence relationship of each indicator. In addition, the DEMATEL method has been fully utilized in enterprise product quality assessment [24], smart product service systems [25], and consumer purchase intention [26]. Compared to the past, which relied on the traditional Kano model for requirements segmentation or the QFD model to realize the conversion between customer requirements and technical characteristics, these methods do not take into account the variability of user weights and the intrinsic connection between requirements when collecting information, which makes the reliability of the assessment results suffer. Compared with traditional design, the requirements of age-friendly design arise from the affinity matching problem in the product design process, which manifests itself in more complex multiple interactions during its life cycle. Therefore, the impact of these relationships on the results of requirements prioritization needs to be fully considered in the process of evaluating requirements for age-friendly design.

Therefore, exploring how to objectively obtain the satisfaction level of elderly users with product age-friendly design requirements during the optimization design process, seeking trustworthy requirement weights, reconstructing smart product interaction prototypes, as well as optimizing human-computer interaction mechanisms constitutes one of the key research contents of age-friendly design for smart products. In terms of age-friendly design demand assessment, based on the exploration of the above issues, the existing assessment process still has the following deficiencies:

(1) In the traditional Kano model, we can directly obtain the weights of product design requirements, but this approach tends to ignore the differences in the individual characteristics of elderly users, which makes the credibility of the evaluation data of each user vary. Different degrees of credibility will have an impact on the ranking assessment of age-friendly design requirements, which in turn affects its objectivity and practicality. Therefore, it is necessary to construct a requirements assessment data integration model that can take into account the varying weights of users in order to reduce the possible influence of group inconsistent assessment data on the results of requirements ranking.

(2) In the process of age-friendly design of smart products, since there may be interdependence or even conflict between the requirements at various stages, the design scheme has a certain degree of ambiguity, which makes the interaction between the age-friendly design requirements an objective phenomenon. Although the DEMATEL method can reveal the extent of the influence relationship, it does not go deep enough when considering the intrinsic influence of multiple demands and their transmission effects on other demands. Therefore, we need to take this into account in the process of calculating demand weights.

(3) In the past research on the demand for age-friendly design, it mainly relied on the subjective preference of experts, which led to large fluctuations in the results of the ranking of demand weights. Therefore, it is necessary to construct a stable and reliable evaluation system and comprehensive weight function, which not only takes into account the satisfaction of the age-friendly design requirements based on the consistency of the population in the optimization evaluation model, but also pays attention to the degree of influence of the conduction utility generated by the interaction of the internal factors of the requirements on the comprehensive weight, so as to improve the quality of the user experience and enhance the loyalty of the users.

B. TECHNOLOGY ACCEPTANCE MODEL APPLICATION

Davis [27] proposed the Technology Acceptance Model (TAM) for the first time based on the Theory of Rational Behavior (TRB) model, supported by the Self-Efficacy Theory (SET) model and the Expectancy Theory (ET) model, which was initially applied to elucidating the causes of information system input-output imbalance as an important theory for exploring the user's acceptance and utilization of information systems. Thanks to its concise structure and strong power to explain user behavior, the model has gained the acceptance of a wide range of researchers and established a basic theoretical framework for studying the factors influencing the use of information systems [28]. The deeply expanded and modified TAM accurately understands and reveals the user's acceptance process of emerging technologies or systems, and it is able to predict and interpret the user's acceptance behavior at a certain level, while showing excellent stability and applicability. Yousafzai et al. [29] summarized and reflected on the empirical research of TAM with the help of meta-analytical methods, adopting a more comprehensive research perspective. Considering the research methodology, technical process and other factors of TAM, a total of more than 70 external variables were found, which cover organizational, individual, system characteristics and other related variables, fully demonstrating the wide applicability of TAM. On this basis, Sohn and Kwon [30] analyzed consumers' acceptance of AI-based smart products based on TAM, expanding the influencing factor variables to verify which factors have the greatest impact on purchase intention. At the same time, TAM still demonstrated excellent statistical analysis strength even with a small sample size required for statistical validation [31]. Therefore, the study takes TAM as the foundation and main theoretical basis to predict the evaluation indexes of the age-friendly design needs of smart products.

Relying on the Theory of Reasoned Behavior framework, TAM identifies perceived usefulness and perceived ease of use as the key elements that dominate the use of information technology. Perceived usefulness reflects the subjective likelihood that users will improve their performance as a result of adopting a technology application in an organizational context, while perceived ease of use was initially defined as the degree to which users are able to use a technology system easily without having to put in too much effort [32]. In view of this, the study classifies the above two as core indicators as exogenous variables. In exploring the design demand indicators that influence the use of new technologies such as smart products by elderly users, the two indicators, perceived usefulness and perceived ease of use, reflect external and internal factors of action, respectively, and have an impact on users' attitude and behavioral tendencies towards application [33]. However, the age-friendly design of smart products is inseparable from human-computer interaction, and considering the uncertain issues and challenges of coordination, fault tolerance, and safety of age-friendly smart products as new products, perceived aesthetics, perceived interactivity, and perceived sociability will also be used as important indicators to influence the use of smart products by elderly users. It has been shown that perceived aesthetics [34], perceived interactivity [35], and perceived sociability [36] are influential indicators of users' attitudes toward use and willingness to demand. Therefore, the study included perceived aesthetics, perceived interactivity, and perceived sociability as exogenous variables in the model, and used them as influence indicators for the needs assessment of age-friendly design.

III. MATERIALS AND METHODS

A. STUDY FRAMEWORK

Aiming at the complex issues involved in the establishment of indicator system, weight allocation, user preference concern and integration of certainty and uncertainty information in the design of smart products considering the needs of the elderly group, the study constructed a framework for evaluating the needs of age-friendly design of smart products, which is shown in Figure 1. The framework consists of four modules:

Evaluation indexes. The theory of the technology acceptance model is the basis to predict the service demand and use willingness of the elderly users, and then establish the preliminary evaluation indexes of the age-friendly design scheme of smart products.

The initial index weights. In order to reduce the influence of subjective factors and verify the accuracy of the evaluation indexes, the TextRank algorithm and Grounded theory are adopted to analyze the demand keywords, finally determine the initial evaluation index weights.

Optimized valuation index weights. In order to identify the relationship between the index factors and determine the importance of each factor, according to DEMATEL's influence factor center degree, cause degree calculation shows the interaction relationship between each evaluation index. At the same time, the particularity of the research target for elderly users is taken into account through questionnaire survey of senior users, so as to further optimize the index weights using the Kano model.

Optimized design of the evaluation scheme: the TOPSIS as a sorting method, considers the distance between positive and negative ideal solutions to realize the sorting of the evaluation indicators. This method is highly objective in the evaluation process and used to screen the most reasonable design evaluation solutions.

Overall, the framework proposed by the study has some strengths:

Based on the two dimensions of perceived usefulness and perceived ease of use in the technology acceptance model, the evaluation indicators are comprehensively determined by combining the demand characteristics of the age-friendly design of smart products and the demand preferences of the elderly users, which strengthens the theoretical support for the selection of indicators.

The weights of the indicators are calculated with full consideration of the demand and preference characteristics of the elderly users, and through the integration of the TextRank Algorithm, Grounded Theory, DEMATEL Method and Kano Model, not only the intrinsic correlation between the indicators is shown, but also the demand and preference characteristics of the users are successfully integrated, which makes the study more academic depth.

In discussing the complexity of the evaluation process, the study notes the elements of ambiguity and uncertainty involved in evaluation information. With the help of evidential reasoning, certainty and uncertainty information is

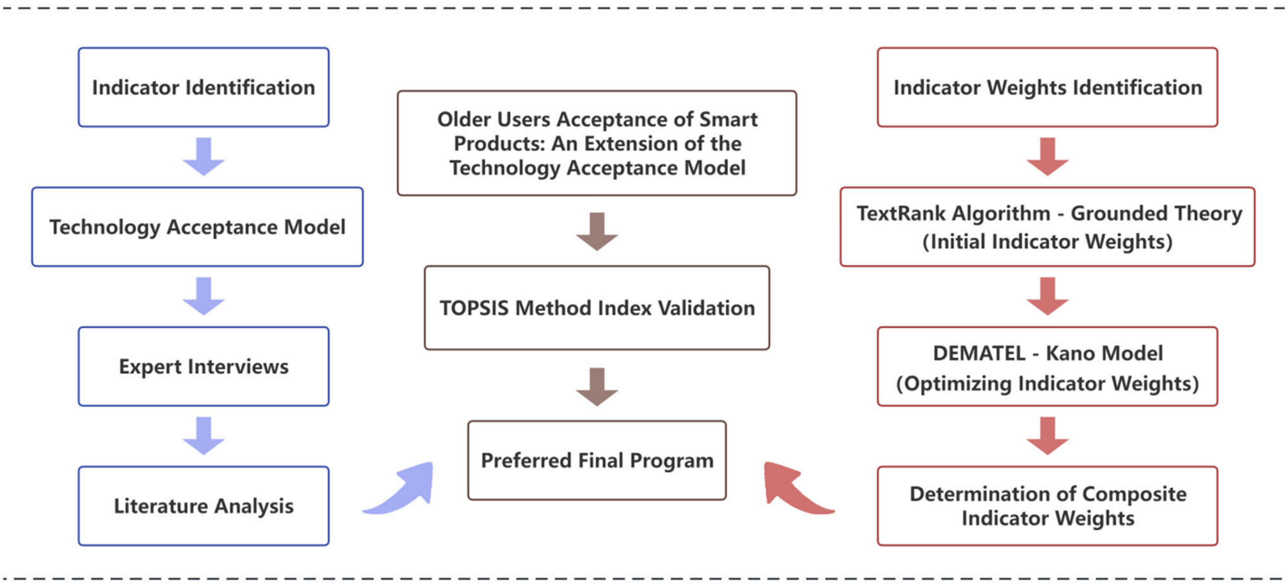

FIGURE 1. Age-friendly design requirements evaluation framework of smart products.

organically combined to obtain a consistent elaboration or description of the test object. This approach provides an effective response to multi-attribute uncertainty decision-making problems, and provides more powerful decision support for the age-friendly design of smart products.

B. EVALUATION INDICATOR SYSTEM

In order to ensure the credibility of the evaluation indexes, the study firstly selects perceived usefulness and perceived ease of use as evaluation indexes based on the technology acceptance model, and the rest of the indexes are adapted from the existing literature, which are appropriately adjusted according to the characteristics of the age-friendly design requirements of smart products. Meanwhile, in order to avoid semantic ambiguities that may reduce the credibility of the evaluation indexes, the study adopts expert interviews to check the acquisition of the evaluation indexes. The study was funded by the National Natural Science Foundation of China (NSFC) and the Provincial University Scientific Research Program. The field and discipline representation of experts is important for the subjective academic evaluation empowerment, and in the process of expert screening and inspection, it is necessary to select experts who are skillful and conscientious to participate in the review. Considering the operational use of smart products and data processing issues, the interview subjects are 10 professorial experts (including associate professors) in the research fields of management, design, and computer science, and the basic information is shown in Table 1. In terms of academic qualifications, the proportion of master's degree and Ph.D. degree is 100%; in terms of titles, the proportion of associate professor and above is 100%; and in terms of years of education/work experience, 90% of the expert scholars have more than 10 years of education work experience. Therefore, this effectively guarantees the authority and scientific nature of the indicators. Meanwhile, considering the objectivity of experts' opinions, this evaluation adopts the method of anonymous invitation, which does not involve the research members within the team, and the experts are not allowed to discuss with each other and have no horizontal connection. By asking them to provide comments on the relevance and meaning of the evaluation indicators, and then modifying the indicators based on their feedback, the evaluation indicators of the age-friendly design requirements of smart products were defined in five dimensions: perceived usefulness (A), perceived ease of use (B), perceived aesthetics (C), perceived Interactivity (D), and perceived Sociality (E). In terms of the credibility analysis of the evaluation indicators, the study used SPSS software to measure the Cronbach's α coefficient value of each indicator variable, and the Cronbach's α coefficient value of each indicator variable was higher than 0.7 [37], which indicates that the evaluation indicators have good credibility, and the specific content and reference sources are shown in Table 2.

C. SAMPLE SELECTION AND DATA COLLECTION

Elderly users have declined in all aspects of physical function, and have higher requirements for the operation of smart products. The smartphone has a greater test for the use of the needs of elderly users in terms of interactive operation, and at the same time, elderly users have certain challenges in the use of the security of the smartphone. In addition, at any time the development of science and technology, the emergence of the elderly digital divide [48], the smartphone's smart interaction attributes are more and more complex, and the intelligence of this feature to bring the elderly users greater trouble. Therefore, from the perspective of the whole

TABLE 1. Expert information.

Expert	Gender	Seniority	Degree	Research Direction	Professional Ranks
1	Male	32	PhD	Design Innovation & Strategy	Doctoral Supervisor (Professor of Management)
2	Female	20	PhD	Social Innovation & Product Design	Master's supervisor (Professor of Design)
3	Male	21	PhD	Technology Innovation Management	Master's supervisor (Professor of Management)
4	Male	30	Master	Product Design	Doctoral Supervisor (Professor of Design)
5	Male	12	PhD	Business Management	Master's supervisor (Associate Professor of Management)
6	Female	9	PhD	User Experience Design	Master's supervisor (Associate Professor of Design)
7	Male	17	Master	Social Innovation Design	Master's supervisor (Professor of Design)
8	Female	15	PhD	Human-Computer Interaction Design	Master's supervisor (Associate Professor of Computer)
9	Female	18	PhD	Information Security	Doctoral Supervisor (Professor of Computer)
10	Male	26	Master	Intelligent Science & Technology	Doctoral Supervisor (Professor of Computer)

TABLE 2. Evaluation indicator system.

Goal Oriented	Indicators	Description	Cronbach's α	Reference
Verification of Age-Friendly Design Solutions for Smart Products	A	Usefulness, Accuracy, Satisfaction, Service Experience	0.706	Sagnier et al. [38] Dasgupta et al. [39]
	B	Learnability, Pioneering, Convenient, Efficient	0.708	Kim et al. [40] Wang et al. [41]
	C	Aesthetics, Periodization, Harmonization, Volume	0.704	Phuong [42] Chaouali et al. [43]
	D	operability, Intuition, Fault Tolerance, Empathy	0.709	Peng et al. [44] Lu et al. [45]
	E	Economy, Timeliness, Respect, Safety	0.707	Li et al. [46] Motamedi et al. [47]

process of smartphone use and its own intelligence, taking into account the characteristics of user clusters and product features, the smartphone is selected as an experimental case, which is representative and typical relative to other smart products. The study collects and organizes 50 samples of adapted aging smartphones through academic websites such as Web of Science, CNKI, and Google Scholar, and e-commerce platforms such as TaoBao, eBay, and Newegg, etc., and uses Web Scraper, a web crawler tool, and on the basis of examining the target website and searching for terms of service related to data crawling, the study crawls the text of the comments related to the target user group from publicly available data sources, and classifies the samples according to the similarity of the appearance data to obtain 20 samples. Finally, experts were invited to screen the 20 samples to identify five age-friendly smartphone samples to form the sample set for the validation of this design requirement evaluation model: Redmi 9A (P_1), VIVO Y53T (P_2), HONOR X50 (P_3), HUAWEI nova 11 (P_4), and iPhone 12 (P_5).

According to the data from the National Bureau of Statistics of China in 2023 [49], the population aging rate of Nantong City was 24.63% in 2022, which ranked first in the country, and as one of the first cities to enter the aging phenomenon, Nantong City has explored the age-friendly research for many years. This study focuses on showing the characteristics and main impacts of smartphone use among Chinese seniors, so the research object is limited to senior smartphone users, and the scope is limited to eight national model senior-friendly communities, which are representative of Nantong City, as shown in Figure 2. The questionnaire was designed in three parts:

(1) A brief description explaining the purpose of this questionnaire and the use of the data, and a brief introduction to the concepts related to smartphones and age-friendly design.

(2) A survey of the basic profile of older users, including information on gender, age, education level, mobile phone use, and socioeconomic situation. The study uses random sampling to conduct in-depth interviews with individual older adults in the sample, with the goal of obtaining older adults' views on smartphones. In order to account for differences within the group, the research will include individuals with different levels of smartphone literacy as much as possible, and will be conducted both online and offline, with the online portion of the study designed to examine individuals with stronger smartphone literacy skills, and the offline portion designed to examine individuals with weaker smartphone literacy skills.

(3) In the main part of the questionnaire, we organized the questionnaire according to the five key indicators of smart product aging design identified in the previous section, with reference to the principles of the Kano model. The questionnaires were distributed and collected both online and offline. In the online questionnaire, we ensured that participants had basic smartphone operating skills by scanning and verifying the QR code, and a total of 710 questionnaires were distributed, of which 672 were validly collected. In the offline survey, we followed the principle of random sampling and first asked the participants, "Can you independently fill in the verification code received on your mobile phone?". If the answer is affirmative, there is no need to continue with the survey; if there are difficulties, the survey will be started; a total of 490 questionnaires were distributed, and 478 were effectively collected. Combining the two methods, we obtained a total of 1,150 valid samples, the effective questionnaire recovery rate is 95.8%, which meets the standard, and the specific statistics are shown in Table 3. Compared with the on-site samples, the online samples are characterized by younger age, higher education level and income level, and they are able to complete the questionnaire independently on the Internet, which shows a strong ability to operate a smart phone.

IV. EMPIRICAL ANALYSIS AND DISCUSSION

A. DETERMINE INITIAL INDICATOR WEIGHTS

1) TEXTRANK ALGORITHM FOR EXTRACTING PERCEPTUAL IMAGERY VOCABULARY

The major goal to extract keywords is to Figure out the words that accurately convey the fundamental semantic information of a document. This process is significant in various fields, including information retrieval, sentiment analysis, and public opinion analysis. Aiming at the problem of poor extraction of words that occur less frequently but can better express the main idea of the text in the keyword extraction task of smartphone adaptive age-friendly evaluation text, the study selected TextRank algorithm to extract the perceptual imagery vocabulary. TextRank algorithm is a sorting algorithm based on graphic analysis used for keyword extraction and data summarization [50]. A graphical model is constructed by splitting the text into a number of keyword elements, constructing keyword nodes, and then establishing edge relationships based on the degree of similarity between the nodes. Ranking the text score by the magnitude of keyword similarity, the score is higher when the similarity between keywords and other keywords is higher. Highly relevant sentences are further refined to generate keywords and digests [51]. This study carefully selects samples to address the complexity and specificity of the needs of elderly smartphone users. The complexity arises from the integration and conflict between the process of digital product construction and traditional elderly services. The specificity is reflected in the weak digital literacy and information expression ability of the elderly. For this reason, when selecting the research sample, we paid special attention to the specificities of older people in their living environment. The principles followed in this study were to emphasize the age distribution and communication skills of the interviewees and to take into account the diversity of their backgrounds. Based on these criteria, we screened 55 older adults from eight communities to participate in the interviews.

This study employs the interactive object elicitation technique, a user research method that involves in-depth interviews. Physical products are used as a medium to elicit user comments. This method has the advantage of increasing user engagement more than picture elicitation methods, ensuring that their comments are not limited to the appearance of the product, but also based on actual experience. Prior

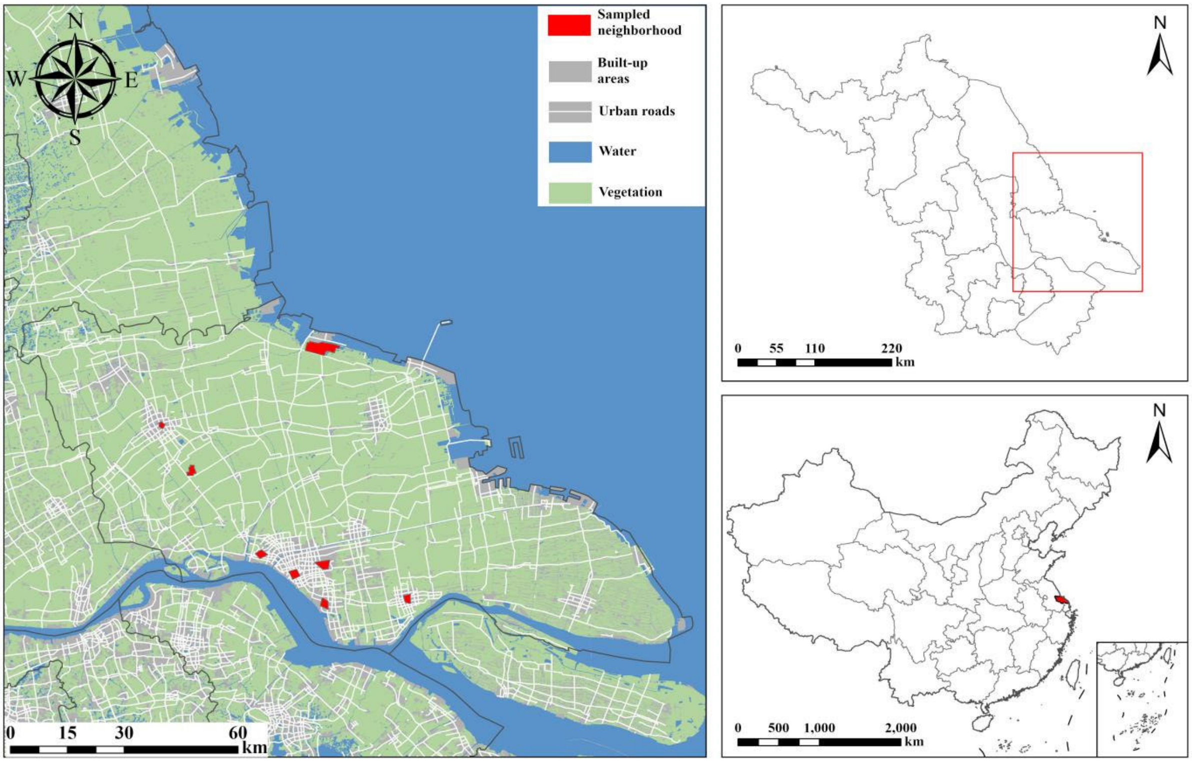

FIGURE 2. Location of the study area.

to the formal interview, the researcher provided a detailed explanation of the meaning of smartphone design to the participants. It was emphasized that the scope of design is not limited to branding and pricing, in order to ensure accurate understanding of the topic of discussion. Following this, the researcher demonstrated and introduced the smartphone to allow participants to experience the product firsthand. Finally, participants were asked to share their perceptions of their experience with the phone in a semi-structured interview guided by the researcher. The interviews followed a semi-structured format, consisting of a set of standardized questions regarding users' perceptions of smartphone usage. The questions focused on eight perspectives: design, presentation, performance, camera, operating system, battery, audio, and functionality. Examples of questions asked include: 'What is your initial impression of the phone?', 'What are your thoughts on the experience of using this cell phone?', and 'Which features do you find particularly convenient?' During the interview, follow-up questions were asked based on the respondents' answers. For instance, when a respondent stated that the cell phone looked sophisticated and was easy to carry, the researcher asked why they thought it looked sophisticated. These questions aided in exploring the underlying meanings behind the respondents' comments and enhancing our comprehension of their mental models and cognitive structures. Ultimately, we compiled and systematically analyzed all the data.

In this study, TextRank algorithm was chosen to select the data of 55 review texts for the five above-mentioned smartphones (P_1-P_5). The essential words were extracted as required key nodes, and their Rank values assessed and sorted using iterative calculation method. Iterative calculation involves the analysis and calculation of the connection relationship between the nodes, and it gradually approximates the Rank value of each node through continuous iterations. This process involves evaluating the nodes' significance by considering factors such as them in-degree and out-degree. It involves obtaining the perceptual imagery word clusters which provide a data source for the required keywords for the rooting theoretical analysis, confirming initial index weights. This process further identifies the needs of elderly user groups with high accuracy and authenticity to enable their effective utilization.

Firstly, 55 comment texts are lexiconized by the HanLP lexer in the Python tool according to the references [52]. Then, comments that are not clearly related to the target user cluster are screened and processed, but key nouns and verbs are screened and remained based on a specified word number threshold. The core words are extracted as nodes of the keyword graph in a quantitative way, following the steps of class delineation, lexical delineation and annotation, and deactivated word deletion. The co-occurrence of the keyword relationship is used to establish connectivity between the nodes and specify the initial value for the nodes. After

TABLE 3. Questionnaire sample information.

Projects	Characteristics	Full-sample		Online Research		Offline Research	
		Frequency	Percentage	Frequency	Percentage	Frequency	Percentage
Sex	Male	632	54.96%	379	56.4%	253	52.93%
	Female	518	45.04%	293	43.6%	225	47.07%
Age groups	60-64	303	26.35%	228	33.93%	75	15.7%
	65-69	431	37.48%	274	40.77%	157	32.84%
	70-74	205	17.82%	102	15.18%	103	21.55%
	75-79	139	12.09%	51	7.59%	88	18.41%
	≥80	72	6.26%	17	2.53%	55	11.5%
Education	Primary and below	336	29.22%	53	7.89%	283	59.2%
	Middle school	439	38.17%	301	44.8%	138	28.88%
	High school	282	24.52%	237	35.26%	45	9.41%
	Bachelor and above	93	8.09%	81	12.05%	12	2.51%
Marriage	With spouse	727	63.22%	461	68.6%	266	55.65%
	Without spouse	291	25.3%	182	27.08%	109	22.8%
	Widowhood	132	11.48%	29	4.32%	103	21.55%
Living area	Urban	668	58.09%	455	67.71%	213	44.56%
	Rural	482	41.91%	217	32.29%	265	55.44%
Incomes (CNY)	0-3999	360	31.3%	162	24.11%	198	41.42%
	4000-7999	593	51.57%	354	52.68%	239	50%
	≥8000	197	17.13%	156	23.21%	41	8.58%
Health	Wellness	601	52.26%	292	43.45%	309	64.64%
	General	379	32.96%	263	39.14%	116	24.27%
	Unhealthy	170	14.78%	117	17.41%	53	11.09%
Occupation	Non-manual	588	51.13%	401	59.67%	187	39.12%
	Worker	440	38.26%	232	34.53%	208	43.51%
	Farmer	122	10.61%	39	5.8%	83	17.37%
Residing status	Living alone	329	28.61%	155	23.07%	174	36.4%
	Living with family	821	71.39%	517	76.93%	304	63.6%
Phone use (Daily)	0-3h	467	40.61%	161	23.96%	306	64.02%
	3-6h	518	45.04%	398	59.23%	120	25.1%
	6-9h	165	14.35%	113	16.81%	52	10.88%

TABLE 4. Representative imagery vocabulary and its weights (partial).

Sample model	Sample display	Imagery vocabulary No.							
		1	2	3	4	5	6	7	8
Redmi 9A		durability	performance	aesthetics	stability	brand	convenience	price	safety
		0.673	0.508	0.465	0.383	0.339	0.276	0.251	0.238
Vivo Y53t		clarity	utility	speed	volume	pixels	battery	signal	capability
		0.861	0.705	0.623	0.492	0.451	0.367	0.303	0.288
Honor X50		screen	battery	image	privacy	performance	ringtones	waterproof	tactility
		0.917	0.858	0.743	0.605	0.592	0.466	0.387	0.325
Huawei nova 11		touchscreen	endurance	durability	brand	fast charge	pixels	safety	weights
		0.898	0.832	0.731	0.653	0.611	0.545	0.449	0.358
iPhone 12		signal	price	brand	performance	memory	battery	localization	pixels
		0.931	0.778	0.652	0.509	0.463	0.407	0.381	0.274

that, the weight value is iteratively propagated between the nodes until convergence. The calculation formula is shown as below:

$$A_{V_i} = \frac{(1-d)}{n} + d\left(\sum_{V_j \epsilon Y_{v_j}} \frac{Z_{ji}}{\sum_{V_k \epsilon X_{v_j}} Z_{jk}} A_{v_j}\right) \quad (1)$$

The formula includes several variables: A_{v_i} represents the importance of the text vocabulary V_i; d represents the damping coefficient with a value of 0.85; Y_{v_j} represents the set of core vocabularies; X_{v_j} represents the set of core vocabularies that co-occur with the text vocabulary V_i; and Z_{ji} and Z_{jk} represent the similarity between the nodes.

The representative imagery vocabulary and weighting coefficients for smartphones were computed and presented in Table 4.

2) GROUNDED THEORY OF ACQUIRING KEYWORDS TO DETERMINE INITIAL WEIGHTS

After acquiring the perceptual imagery vocabulary and corresponding weight coefficients through the TextRank Algorithm, to further refine and categorize the imagery vocabulary is needed. Also, it is necessary to extract the core keywords to be organized in the evaluation indexes of aging-appropriate design of smart products and compute the initial weight value of each index. Grounded Theory as a bottom-up systematic inductive approach can inductively organize the categories, naming and connotations of research design demand indicators from the perspective of the user subject, minimizing the influence of the object. Therefore, the research adopts a combination of quantitative analysis and qualitative researches, focusing on the requirements of elderly user clusters. Furthermore, the Grounded Theory approach is utilized in refining the evaluation scope of smartphone age-friendly design, selecting out keywords, and setting the initial weights of exceptional features.

The grounded theory method, as a qualitative research, emphasizes developing a theory from empirical information [53]. The method's primary aim is to derive general principles and laws from detailed observations and analysis of actual situations, finally concluding a practical theoretical framework. Firstly, in the bottom-up research approach, systematically collected information is used to identify core concepts that accurately represent social phenomena, and then develop related social theories. To be noted, grounded theory is based not solely on empirical factors, but also on innovative concepts and ideas derived from empirical facts, validated by robust evidence [54]. Relying on the smart products age-friendly design demand evaluation index system, the raw data in the comment text are coded in open-ended, spindle-ended and selective coding through conceptual summarization, and the details are shown in Tables 5-6.

(1) Open coding. After integrating, analyzing and refining the initial data, the labeling, conceptualization and categorization of the data were achieved [55]. The study used the qualitative analysis software Nvivo 14 to initially code the review text, complete the concepts and categories of free

TABLE 5. Partial spindle coding process.

Subcategory	Initial category	Primary sources (partial)
System stability	Fast software installation	...Installing software is typically convenient and quick. The process is fast and does not interfere with making calls or reading text messages...
	Runs without lag or flicker	...I did not observe any flickering or frame drops on the phone during my usage, indicating a stable performance...
Content usefulness	Redundancy streamlined	...Comes with a full range of software, no extra ads, know at a glance what the software does...
	Push content valueability	...regular publication of relevant content that is relatable and valuable to our daily lives...
User friendliness	Smooth running screen	...The process of using it thus far has been very smooth, and the apps install quickly...
	Well-designed interface	...The phone screen is large and the interface design is suitable for our age group...
Operational fluency	Fast and accurate search	...I can easily locate the video software I need and promptly send messages...
	Smooth animation transition	...The animated transition is preferred. The system is well optimized and responsive...
Interface aesthetics	Sensory experience	...creates a user interface to provide a positive user experience. As a user, I appreciate this feature...
	Clear and intuitive layout	...The layout is square, and all the necessary software is easily accessible on one page...
Design aesthetics	Good looking design	...The built-in applications and overall design are aesthetically pleasing, with a natural color scheme...
	Lightweight and Portable Simplicity	...Not only is it lightweight and has a large screen, but it is also easy to carry without having to pack it in a bag...
Functional interactivity	Search Referral Interactive	...The search function is efficient. By using keywords, users can easily find what they are looking for...
	Audio-Camera Interactive	..The camera automatically focuses when taking pictures, adjusts beauty settings, and adjusts volume based on the environment...
Functional completeness	Intelligent classification	...can be organized into groups based on the user's habits...
	Convenient and versatile	...including helpful features like automatic localization, voice broadcasting, and news notifications...
Application security	Payment Security	...The payment process is quick, and you can use fingerprints and facial recognition for multiple methods of buying...
	Privacy and Security	...Personal privacy is well-protected, and the accompanying system safeguards all of my private information...
Timely feedback	Efficiency of user feedback	...More valuable feedback features, such as the ability to quickly resolve common advertising issues...
	Feedback Guidelines	...There are problems such as ad skipping while watching the news, is there an exclusive customer service to provide help...

TABLE 6. Selective coding process.

Main category	Subcategory	Category connotation
Perceived Usefulness (79)	System stability(45)	No errors occurred during the loading and running of the phone.
	Content usefulness(34)	The presentation of content and information should be tailored to meet the needs of older users while also providing value.
Perceived Ease of Use (152)	User friendliness(77)	The interface design aligns with the logic and habits of elderly users' daily use.
	Operational fluency(75)	Smooth browsing, switching, and downloading during loading and operation.
Perceived Aesthetics (69)	Interface aesthetics(37)	The design of each panel of the cell phone interface is aesthetically pleasing.
	Design aesthetics(32)	The phone's design is aesthetically pleasing, with attractive styling and colors.
Perceived Interactivity (171)	Functional interactivity(79)	Communication with the platform via cell phone is possible.
	Functional completeness(92)	Complete the task by adding both basic and additional features.
Perceived Sociality (137)	Application security(81)	Downloading and installing apps on cell phones is not harmful to the device's system.
	Timely feedback(56)	Issues and challenges experienced while utilizing the process can be quickly addressed and resolved.

TABLE 7. Initial indicator weights.

Indicator-level indicators	A	B	C	D	E
Weights B_i	0.1299	0.2500	0.1135	0.2813	0.2253

nodes and tree nodes, and obtain 608 initial concepts. After sorting, extracting, analyzing, summarizing, and deleting steps, 20 initial categories such as fast software installation, redundancy streamlined, smooth running screen, and intelligent classification were generated.

(2) Spindle coding. Based on the spindle-based coding strategy, the purpose is to deeply excavate the intrinsic connection between the concept and many categories, and to realize the correlation elaboration and reasonable presentation of the components of the original data [56]. Based on the 20 initial categories obtained by open coding. After comprehensive generalization and aggregation analysis, these initial concept attributes and dimensions are specified, and the data are reintegrated to obtain the intermediate factors of the age-friendly design demand indicators of smart products, forming 10 secondary categories such as system stability, content usefulness, user friendliness, application security, etc.

(3) Selective coding. Under the precondition based on specific logical connections, secondary categories, initial categories and initial concepts are categorized and integrated to explore the representativeness and coherence among concepts [57]. Through repeated comparison and argumentation, it is found that there is a strong logical relationship between perceived usefulness, perceived ease of use, perceived aesthetics, perceived interactivity, and perceived sociability, which is in line with the composition of the evaluation system of the age-friendly design needs of smart products.

(4) Saturation test. When the coding of information data can no longer present further novel ideas, categories and associations, three or more sources can be verified. If novel categories and associations can still not be identified through verification, then it can be judged that the theory derived from the code has achieved saturation [58]. The study did a theory saturation test on 20 randomly selected textual materials from 55 review texts. After three levels of coding and analysis, no new categories and associations were identified, so the final sample marked theory saturation.

(5) Initial indicator weight calculation. Calculate the initial indicator weights of the smart product age-friendly design demand indicators according to the coding results, and the calculation results are shown in Table 7.

B. OPTIMIZATION OF INDICATOR WEIGHTS

1) DEMATEL METHOD WEIGHTS CALCULATION

The DEMATEL algorithm, developed by professors Gabus and Fontela of the Geneva Research Center in the 1970s,

TABLE 8. Initial direct impact matrix.

Evaluation indicators	A	B	C	D	E
A	0	0	0	1	2
B	2	0	1	3	3
C	0	0	0	2	1
D	2	3	2	0	3
E	0	2	0	1	0

TABLE 9. Calculation of indicator value.

Evaluation indicators	F_i	G_i	H_i	I_i	J_i
A	0.7079	0.9907	1.6986	-0.2828	0.126
B	2.0684	1.3830	3.4514	0.6854	0.255
C	0.8354	0.7524	1.5877	0.0830	0.117
D	2.2095	1.5704	3.7799	0.6392	0.280
E	0.9346	2.0594	2.9940	-1.1248	0.222

is an algorithm used for factor analysis of complex systems. This algorithm utilizes the principle of graph theory and builds an analytical structure model to recognize and analyze the causal correlations between complex social factors, so as to identify key elements [59]. Its application, as a scientific analytical tool, is significant in decision-making of complex systems [60]. The DEMATEL method allows for quantitative analysis of the mutual influence degrees between elements, including influence degree, degree of being influenced, along with cause and centrality of each element. This method obtains weight values between the elements considering interrelationships between indicators, so as to adjust and optimize the weight interference due to the non-independence between the product design evaluation indicators [61]. According to Table 1, the evaluation index's importance differs with mutual influence. In order to calculate the weight value of the indexes, the study referred to the DEMATEL method in the literature [62] and the following specific steps were followed:

(1) To develop the initial direct impact matrix. Firstly, experts were invited to judge the strength of the impact between the indicators, which was transformed into non-negative integers using the five-point method [63] according to a five-level scale of 0 - none, 1 - weak, 2 - normal, 3 - strong, and 4 - very strong. Then, a directional map is drawn to represent the corresponding score of each indicator, as shown in Figure 3. Through that, the initial direct impact matrix is built, $C = \left\{x_{ij}\right\} n \times n$ (refer to Table 8).

(2) Direct Impact Matrix (Normalized). Matrix C is then normalized and take as D by the following formula:

$$D = \frac{x_{ij}}{\max(\sum_{i=1}^{n} x_{ij})}(1 \leq j \leq n) \tag{2}$$

(3) To calculate the integrated impact matrix. The integrated impact matrix E follows this formula:

$$E = \left(Y + Y^2 + Y^K\right) = \sum_{K=1}^{\infty} Y^k = Y(I - Y)^{-1} \tag{3}$$

(4) To calculate the influence degree, influenced degree, center degree, cause degree and weight value of each element The calculation results are shown in Table 9.

The degree of influence, denoted as F_i, is the sum of each row's values in matrix E. This value represents the comprehensive influence of each element, in a row, on all other elements.

$$F_i = \sum_{J=1}^{n} x_{ij}, (i = 1, 2, \ldots, n) \tag{4}$$

The degree of influence is determined by summing the values in each column of matrix E, which represents how much all the elements in a column influence each other element. This value is denoted as G_i and calculated through the following formula:

$$G_i = \sum_{j=1}^{n} x_{ij}, (i = 1, 2, \ldots, n) \tag{5}$$

TABLE 10. Categorization of user demand preferences.

Evaluation Indicators	A	O	M	I	Total	Kano Category
A	327	385	271	167	1150	O
B	218	495	256	181	1150	O
C	259	296	441	154	1150	M
D	396	283	289	182	1150	A
E	264	303	405	178	1150	M

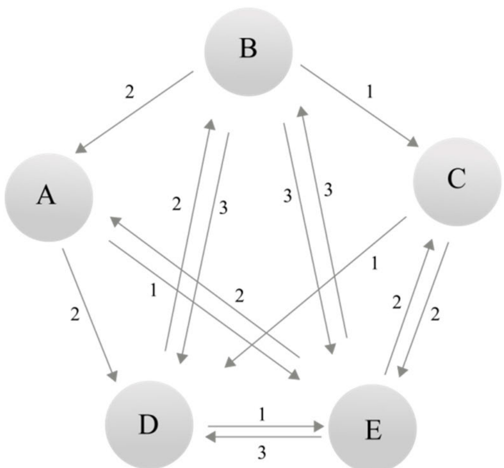

FIGURE 3. Directional map of evaluation indicator relationships.

FIGURE 4. Kano model.

The central degree refers to the position of a factor in the evaluation system and its significance. The central degree of a factor is quantified by summing up its degree of influence over the degree of influence being exerted on it, indicated as H_i. The corresponding formula is as follows:

$$H_i = F_i + G_i \tag{6}$$

Then the degree of causation can be determined, and the degree of influence of the element from the degree of being influenced is subtracted, both represented as I_i, by the following formula:

$$I_i = F_i - G_i \tag{7}$$

Then the inter-indicator impact weights can be calculated, denoted as J_i, according to the following formula:

$$J_i = \frac{H_i}{\sum_{i=1}^{n} H_i} \tag{8}$$

2) KANO MODEL WEIGHTS ADJUSTMENT

The Kano model was introduced in 1984 by Japanese scholar Noriaki Kano [64] It categorizes the quality attributes of a product into five types that are based on the correlation between its objective performance and customers' subjective perceptions. These categories include Must-have quality (M), Expected quality (O), Attractive quality (A), Undifferentiated quality (I), and Reversed quality (R) [65], as shown in Figure 4. Through this model, the satisfied and unsatisfied needs of elderly users can be effectively segmented in a more scientific way, enabling a more accurate identification of different user groups. Among aging-friendly smart products, users are always the major design focus by comprehensively considering the user's characteristics and behavioral needs [66]. Peng et al. [67] argued that the fused DEMATEL - Kano modeling approach is more reliable by better taking into account the interactions between evaluation metrics as well as the importance of the user in program selection and the comprehensive integration of deterministic and uncertainty information. To realized higher evaluation effectiveness, the Kano model combined with questionnaires can be used to measure relevant indexes, so as to understand the differences and preferences between user needs.

According to the 1150 questionnaires collected above, the Kano classification results of smart product age-friendly

TABLE 11. Kano model evaluation indicator weights.

Indicator-level Indicators	A	B	C	D	E
Weights L_i	0.2	0.2	0.1	0.4	0.1

TABLE 12. Composite indicator weights.

Indicator-level indicators	A	B	C	D	E
Weights K_i	0.0608	0.2367	0.0246	0.5850	0.0929

TABLE 13. Initial evaluation matrix.

Evaluation Indicators	Age-friendly Smartphone Product Sample				
	P_1	P_2	P_3	P_4	P_5
A	7.6	7.8	8.2	8.0	7.8
B	7.8	8.0	8.0	7.8	7.6
C	7.6	7.8	8.2	8.0	7.8
D	7.6	7.8	8.2	8.0	8.0
E	8.2	8.0	7.8	7.8	7.8

design demand indicators are determined with reference to the frequency maximum method, which is shown in Table 10. This study refers to the Kano model weight optimization method in the literature [68], and sets 0, 1, 2, and 4 as the adjustment coefficients μ corresponding to the Kano attributes I, M, O, and A, in which L_i is the adjusted weight and J_i is the indicator influence weights between them, the calculation results are shown in Table 11, and the calculation formula is:

$$L_i = \frac{J_i\mu}{\sum_{j=1}^{n} J_i\mu} \tag{9}$$

3) DETERMINATION OF COMPOSITE INDICATOR WEIGHTS

TextRank Algorithm is adopted to obtain the perceptual image vocabulary, and Grounded Theory analysis of the required keywords is utilized to determine the initial indicator weights. Such combination of quantitative analysis and qualitative research can effectively reduce the interference of subjective factors. Moreover, the mutual influence of evaluation indicators between the weights can be adjusted by the DEMATEL method, and further optimization of evaluation indexes can be realized by the Kano model. The combination of the above four research methods can better analyze the important role of evaluation indexes in the verification of age-appropriate design solutions for smart products, and determine the weights of the comprehensive indexes, which are calculated by the following formulas, as shown in Table 12.

$$K_i = \frac{J_iB_iL_i}{\sum_{i=1}^{n} J_iB_iL_i} \tag{10}$$

C. TOPSIS SELECT MORE FAVORABLE DESIGN EVALUATION PROGRAM

TOPSIS, which stands for Technique for Order of Preference by Similarity to Ideal Solution, is a scientific method widely used to analyze multi-objective decisions with finite solutions. The method functions by first normalizing the original matrix, defining the optimal and worst solutions among various options. Then, it calculates the distance between the evaluation objects, identifying the best and worst solutions. Then, the proximity of the evaluation object to the ideal program is calculated, to serve as the basis for evaluating the pros and cons [69]. The application of this method is conducive to informed assessments and decisions for best results.

Before the formula calculation, according to the previous summary of a number of smart product age-friendly evaluation categories cannot be directly quantified to design the evaluation scheme, the construction of the initial evaluation matrix is conducive to a better analysis of the evaluation

TABLE 14. Standardization of evaluation matrices.

Evaluation Indicators	Age-friendly Smartphone Product Sample				
	P_1	P_2	P_3	P_4	P_5
A	0.431	0.443	0.465	0.454	0.443
B	0.445	0.456	0.456	0.445	0.434
C	0.431	0.443	0.465	0.454	0.443
D	0.429	0.440	0.463	0.452	0.452
E	0.465	0.454	0.443	0.443	0.443

TABLE 15. Weighted evaluation matrix.

Evaluation Indicators	Age-friendly Smartphone Product Sample				
	P_1	P_2	P_3	P_4	P_5
A	0.026	0.027	0.028	0.028	0.027
B	0.105	0.108	0.108	0.105	0.103
C	0.011	0.011	0.011	0.011	0.011
D	0.251	0.257	0.271	0.264	0.264
E	0.043	0.042	0.041	0.041	0.041

model of the scheme sorting preferences. By inviting experts to score the evaluation indexes in Table 2, according to the Likert 9-level scale (1-9) [70], around five samples of age-friendly smartphones (P_1-P_5), counting the scores and calculating the average value, the initial evaluation matrix is constructed, see Table 13, and in order to improve the performance of the data, enhance the precision of the matrix model, and simplify the calculations, the matrix is standardized again [71], see Table 14.

In this study, we refer to the TOPSIS formula in the reference [72], and the calculation process is as follows:

(1) To build the evaluation data matrix for ageing-friendly design of smart products. The horizontal indexes should be the evaluation ones, represented by m; the vertical indexes as case samples, represented by n. Then the obtained data is normalized to build the matrix $U = \begin{pmatrix} u_{11} & \cdots & u_{1m} \\ \vdots & \ddots & \vdots \\ u_{n1} & \ldots & u_{nm} \end{pmatrix}$, and the raw data is normalized to have the matrix V_{ij}. The normalized values in the matrix are:

$$V_{ij} = \frac{u_{ij}}{\sqrt{\sum_{i=1}^{n} u_{ij}^2}} \tag{11}$$

(2) To standardize the weights to build a weighting matrix. Matrix Z_{ij} adjusts the weights using the comprehensive weight formula K_i and the standard normalization matrix V_{ij}. Table 15 presents the results of the weighting process.

$$Z_{ij} = K_i V_{ij} (i = 1, 2, \ldots, n; j = 1, 2, \ldots, m) \tag{12}$$

(3) To calculate the positive and negative ideal solution values. The calculation formula is as follows:

$$Z^+ = (z_1^+, z_2^+, \ldots, z_m^+ = (\max\{z_{11}, z_{21}, \ldots, z_{n1}\}, \max\{z_{12}, z_{22}, \ldots, z_{n2}\}, \ldots, \max\{z_{1M}, z_{2M}, \ldots, z_{nm}\}) \tag{13}$$

$$Z^- = (z_1^-, z_2^-, \ldots, z_m^- = (\min\{z_{11}, z_{21}, \ldots, z_{n1}\}, \min\{z_{12}, z_{22}, \ldots, z_{n2}\}, \ldots, \min\{z_{1M}, z_{2M}, \ldots, z_{nm}\}) \tag{14}$$

(4) To calculate the Euclidean distance. The calculation formula is as follows:

$$O_i^+ = \sqrt{\sum_{j=1}^{m} (z_j^+ - z_{ij})^2} \tag{15}$$

$$O_i^- = \sqrt{\sum_{j=1}^{m} (z_j^- - z_{ij})^2} \tag{16}$$

(5)To establish sorting preferences for the comprehensive evaluation index, calculate the relative affinity as follows: Define S_i as the formula for computing the relative closeness;

TABLE 16. Closeness degree.

Euclidean Distance and Nearness Degree	Age-friendly Smartphone Product Sample				
	P_1	P_2	P_3	P_4	P_5
O_i^+	0.020	0.014	0.002	0.007	0.009
O_i^-	0.003	0.008	0.021	0.014	0.013
S_i	0.130	0.364	0.913	0.667	0.591
Rank	5	4	1	2	3

TABLE 17. Comparative ranking of W1-W4 empowerment methods.

Nearness Degree	Empowerment Methods	Age-friendly Smartphone Product Sample				
		P1	P2	P3	P4	P5
Sample Collection S_i Score	W1	0.328	0.473	0.717	0.546	0.434
	W2	0.313	0.474	0.739	0.559	0.474
	W3	0.156	0.390	0.893	0.649	0.587
	W4	0.141	0.382	0.910	0.655	0.609
	W5	0.130	0.364	0.913	0.667	0.591
S_i Normalization	W1	0.13	0.19	0.29	0.22	0.17
	W2	0.12	0.19	0.29	0.22	0.19
	W3	0.06	0.15	0.33	0.24	0.22
	W4	0.05	0.14	0.34	0.24	0.23
	W5	0.05	0.14	0.34	0.25	0.22
Preferred Ranking of Options	W1	5	3	1	2	4
	W2	5	3	1	2	4
	W3	5	4	1	2	3
	W4	5	4	1	2	3
	W5	5	4	1	2	3

larger S_i values correspond to more logical indicators. The formula is shown below, and the computation results are presented in Table 16.

$$S_i = \frac{O_i^-}{O_i^- + O_i^+} \tag{17}$$

V. VALIDATION OF CASE RESULTS

To establish the ranking preference for the evaluation scheme, it is necessary to verify the method's rationality and priority. As a result, the design scheme preference under different weight assignment methods are compared. More specifically, W_1 is based on TextRank Algorithm - Grounded Theory

TABLE 18. Comparison of weight values of W1-W4 empowerment methods.

Empowerment Methods	A	B	C	D	E
W_1	0.1299	0.25	0.1135	0.2813	0.2253
W_2	0.0737	0.2869	0.0598	0.3545	0.2251
W_3	0.11683	0.22484	0.05104	0.50598	0.10131
W_4	0.0608	0.2367	0.0246	0.5850	0.0929

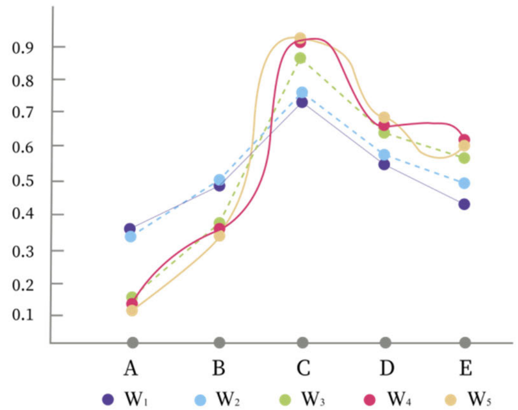

FIGURE 5. Comparison of normalization of W_1-W_4 empowerment methods.

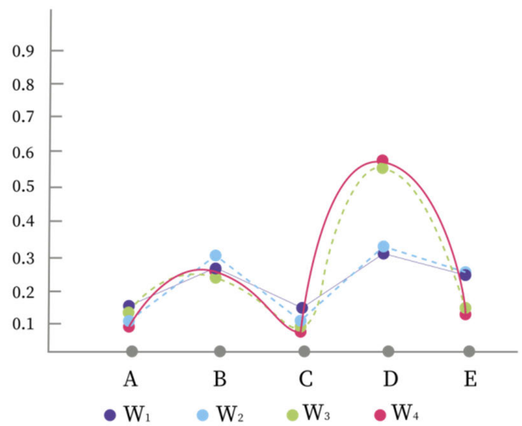

FIGURE 6. Comparison of weights of W_1-W_4 empowerment methods.

- TOPSIS, which does not consider the influence between evaluation indicators and the influence of user demands on evaluation indicators; W_2 on TextRank Algorithm - Grounded Theory - DEMATEL - TOPSIS; W_3 on TextRank Algorithm - Grounded theory - Kano model - TOPSIS, with considerations user demand's influence on evaluation indicators; W_4 on TextRank Algorithm - Grounded theory - DEMATEL - Kano model - TOPSIS, considering the comprehensive influence between evaluation indexes and the influence of user demand on evaluation indexes. In addition, the relative closeness S_i in Table 16 is responsible for the W_5 result. To guarantee the comparability of the four assignment methods, this study eliminates the decimal fractions from the subsequent calculations. Moreover, consistently numerical calculations are performed directly to ensure that the comparisons of the W_1-W_4 schemes are consistent. The difference between the calculation results of W_4 and W_5 is attributed to the errors produced by remaining the decimal point during the calculation process. The effect on the preferred ranking of evaluation indicators is minimal and not significant. Tables 17 - 18 and Figures 5-6 present the calculation results.

According to these results, the evaluation schemes of W_1 and W_2 empowerment methods have a consistent order. W_1 is based on TextRank - Grounded theory, and W_2 on TextRank - Grounded theory - DEMATEL. However, the group characteristics and use requirements of the elderly were not considered during the empowerment process. Referring to Figure 5, curves in W_1 and W_2 empowerment methods are relatively flat, which results in less differentiation between the evaluation indexes' weights. Therefore, the similarity of the evaluation schemes' results tends to be higher. Referring to Figure 6, curves in the W_1 and W_2 empowerment methods are also relatively smooth, which indicates insufficient differentiation between the evaluation indicators regarding their respective weights. That is, this leads to a high degree of similarity in the evaluation program's results and less differentiation. However, the evaluation programs for the W_3 and W_4 assignment methods follow a similar pattern. As demonstrated in Figure 6, the weight differentiation between the evaluation indicators of W_4 is more significant comparing to that of W_3. This indicates that comprehensively considering the user's needs and the weight influence between indicators is more reasonable and beneficial for selecting the design program. Therefore, the TextRank Algorithm - Grounded Theory - DEMATEL - Kano Model - TOPSIS Design Requirements Evaluation Model meets the research needs and helps to guide the improvement of smart product age-friendly solutions.

VI. CONCLUSION

The study proposes an evaluation scheme for age-friendly smart product design requirements based on Technology

Acceptance Model, which fully considers the characteristics of the elderly users and the aging characteristics of the product. In addition, TextRank Algorithm, Grounded theory qualitative research method, DEMATEL decision experiment and evaluation analysis method, Kano model method, and TOPSIS approximation of the ideal solution ranking method are combined to build an evaluation system systematically and rationally by incorporating a five-dimensional index system, including perceived usefulness, perceived ease of use, perceived aesthetics, perceived interactivity, and perceived sociability. In this study, five types of smartphones are taken as representative smart product samples, so as to assess whether the evaluation index system can meet target users' needs. Based on the evaluation index system, current designs for age-friendly smart products should prioritize users' experience and inherent preferences, focusing on products' perceived interactivity and ease of use. The study contributes to the scientific evaluation of age-friendly design requirements of smart products, stepping forward comparing to previous researches and providing a theoretical foundation for related departments' evaluation of age-friendly products. Furthermore, the study develops an evaluation index system to determine the favor level of age-friendly smart product design and provides practical recommendations for future practice. However, this study also has limitations as indexes at all levels are somewhat subjective, and data collection for some indexes can be challenging. Therefore, further improvement is required. Moreover, only a few representative smartphones were selected, so future researches can expand the scope, so as to have more reasonable results. Age-friendly renovation is a crucial requirement for implementing modern intelligent elderly care, and it has become a core strategy for the international community to address the trend of population aging. China is in the early stages of aging governance, facing challenges such as the delayed emergence of aging, inadequate early research foundation, and relatively limited practical experience in the governance system. Furthermore, the scope of related research remains limited and the factors considered are not comprehensive enough, which hinders the effectiveness of the renovation. To improve the effectiveness of age-friendly renovation, China should analyze and learn from successful international cases. For example, China could learn from the inclusive elderly care system in Eastern Europe, the market-oriented large-scale elderly communities in the United States, the community care model in the United Kingdom, and the nursing care insurance system in Japan. China can develop standardized recommendations and an implementation roadmap by summarizing typical practices and advanced experiences of other countries. This will effectively alleviate the current contradiction between environmental facilities and the needs of an aging society, promoting the healthy development of the elderly care industry.

DATA AVAILABILITY STATEMENT

The data used to support the findings of this study are all in the manuscript.

CONFLICT OF INTEREST

The authors declare that they have no competing interests.

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HUI ZENG received the B.S. degree in animation from the Communication University of Shanxi, China, in 2020, and the M.S. degree in art from Anhui University of Finance and Economics, China, in 2023. He is currently pursuing the Ph.D. degree in design with Jiangnan University, China. His research interests include design innovation and strategy, sustainable design, age-friendly design, and crowdsourced design.

JINWEI ZHU received the B.S. degree in management engineering from Chongqing University, China, the M.S. degree in management from Fudan University, China, and the Ph.D. degree in management from Hitotsubashi University, Japan. He is currently a Professor with Jiangnan University. He was the Director of Wuxi Human Resource Development Research Base, the Vice President of Jiangsu Human Resources Society, and an Advisor of the Social Construction Committee of the 17th People's Congress of Wuxi City. His research interests include human resource management, strategic management, innovation and entrepreneurship management, and multinational business management.

HANXI LIN was born in Fuzhou, Fujian, China, in 2002. She is currently pursuing the B.S. degree in visual communication design with Dalian Polytechnic University, China. Her research interests include social innovation design, graphic design, smart product packaging, and service system design.

JUNMING CHEN received the M.S. degree in digital media art from Macau University of Science and Technology, China, where he is currently pursuing the Ph.D. degree with the Faculty of Humanities and Arts. He is a Researcher with Macau University of Science and Technology. His research interests include machine learning, deep learning, digital fabrication, architectural design, and generative design.