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Development and validation of an ageing-oriented smart products design framework based on technology acceptance model (TAM)

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ABSTRACT

With the global prevalence of diabetes among the elderly on the rise, integrating smart product technologies into daily healthcare offers a promising solution. This study examines the key variables influencing elderly individuals' acceptance of smart products to develop an ageing-oriented smart product design framework. A literature review and questionnaire were conducted to identify determinants of technology acceptance. To ensure robustness and practical applicability, the proposed framework was subsequently validated through expert review. The findings reveal that behavioural intention (BI) serves as the central variable influencing elderly users' acceptance, while perceived ease of use (PEOU), perceived usefulness (PU), perceived enjoyment (PE), and self-efficacy (SE) emerge as significant internal predictors of BI. Among the external variables, appearance design (AD), function design (FD), and interface design (ID) exert the strongest indirect effects on BI through their influence on PEOU. Based on these relationships, a smart product design framework tailored for diabetic elderly was constructed. This study advances the understanding of the structural relationships between TAM variables and product design factors, providing both theoretical insights and practical guidelines for the development of smart products for diabetic elderly, with broader implications for the ageing population. Future research will further explore the daily needs of diabetic elderly and incorporate usability testing in real-world settings to implement and refine the framework.

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technology acceptance
model; smart products;
conceptual framework;
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> IMPLICATIONS FOR REHABILITATION

1. The elderly groups are at high risk of developing type 2 diabetes, which presents serious challenges to the elderly's life quality due to its complications and the associated rehabilitation process.
2. Untreated diabetes among elderly groups will lead to serious complications, affecting their rehabilitation of health and compromising life quality.
3. Previous studies have demonstrated that a healthy diet can reduce complications and benefit rehabilitation for diabetic elderly groups. However, elderly groups often face difficulties learning healthy knowledge and accepting new technologies compared to younger people. There is a scarcity of research gap on technology acceptance among older adults.
4. This study indicates that the ageing technology acceptance model has significant potential to guide healthy diets in diabetic elderly.
5. Policymakers, researchers, designers, and other stakeholders can refer to this study's outcomes and this ageing technology acceptance model can enhance diabetes management and rehabilitation strategies for diabetic elderly.

Introduction

The prevalence of diabetes among elderly people is increasing worldwide, presenting a serious challenge to government healthcare systems and ageing care services [1]. With the advent of diabetes among elderly people, managing diabetes has become increasingly complex, because elderly people often

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contend with comorbidities, medication regimens, and lifestyle adjustments [2]. In particular, elderly people are confronted with challenges related to cognitive decline, including memory deficits and difficulties in adapting to new technologies [3]. Moreover, a healthy diet represents a pivotal lifestyle factor in the management and mitigation of diabetes onset among the elderly population. Consequently, there is an urgent need for innovative interventions to support the diabetic elderly population in effectively managing their condition and maintaining a healthy diet lifestyle [4]. However, existing approaches often fall short of addressing this demographic's unique needs and challenges, highlighting the necessity for tailored solutions that prioritise usability, acceptance, and efficacy.

In recent years, there has been a remarkable surge in the development and adoption of smart products to promote healthcare [5]. Ranging from wearable devices, Internet of Things (IoT) devices, mobile applications and smart home appliances that integrate technology into daily smart products has revolutionised how individuals monitor and manage their health [4]. This proliferation of smart products has been driven by advancements in sensor technology, data analytics, and connectivity, offering unprecedented opportunities for personalised healthcare interventions, especially by providing a blue market for the healthy diet of diabetic elderly people [6]. As such, there is growing interest in leveraging these technologies to develop smart products specifically tailored to meet the needs of diabetic elderly people [7].

Despite the potential benefits of smart products in facilitating a diabetes diet, the acceptance of these products among elderly people remains a considerable gap in investigation [8]. Notably, the technology acceptance model (TAM), a widely recognised model in the field of information systems research, provides valuable insights into the variables influencing individuals' acceptance and adoption of technology [9]. By examining the perceived usefulness and ease of use of smart products designed for elderly people through TAM, researchers can gain a deeper understanding of the variables influencing elderly people's acceptance and contribute to more user-centric smart product design [10].

Therefore, this paper aims to investigate the variables influencing elderly people's acceptance and adoption of smart products to propose an ageing-oriented smart product design framework. The proposed framework will be validated through expert review to ensure its robustness and practical applicability. This design framework can provide valuable insights for designers, healthcare practitioners, and policymakers seeking to develop tailored interventions that empower diabetic elderly individuals to lead healthier lives in the future.

Literature review and hypotheses

Diabetic elderly and smart products

Diabetic elderly people represent a significant demographic group within the context of smart products [11]. With the prevalence of diabetes among elderly individuals increasing globally, integrating smart product technologies into healthcare management holds promise for improving outcomes [12]. In the IoT and smart products context, a variety of platforms and products are utilised to monitor, track, and manage health parameters in real time, providing a comprehensive approach to care [13]. Specifically tailored smart product services cater to the unique needs of diabetic elderly people, offering personalised solutions for monitoring blood sugar levels, medication adherence, and lifestyle management [14]. The implementation of smart products in elderly healthcare has gained traction, with various studies exploring their effectiveness in disease management and preventative care. As facilitators in the healthcare process, smart products enable continuous monitoring and timely intervention, enhancing the quality of care provided to diabetic elderly patients [6].

In comparison to traditional healthcare approaches, smart products offer several advantages, including remote monitoring, early detection of complications, and improved patient engagement. Smart products are technologically advanced devices that integrate components such as sensors, wireless communication, and data processing to deliver enhanced functionality, real-time interaction, and personalised experiences. These products are typically connected to the Internet of Things (IoT), enabling them to adapt to user behaviour and environmental conditions. The interface design of smart products plays a crucial role in ensuring usability and user acceptance, especially for older adults. In the context of this study,

smart products refer specifically to digital solutions aimed at supporting older adults living with type 2 diabetes in managing their health—particularly diet and glucose monitoring—through intuitive, accessible, and user-centered interfaces.

However, to fully harness the potential of smart product healthcare solutions, understanding the perspectives and preferences of diabetic elderly users is essential [15]. Research indicates that the perceptions and preferences for adopting new technology among diabetic elderly people are nearly identical to those of the general elderly population [16]. Therefore, the purpose of this research is to investigate the usability, acceptance, and impact of smart product technologies among diabetic elderly people, aiming to inform the development of user-centered smart product healthcare solutions tailored to their needs.

The original technology acceptance model and elderly acceptance

TAM serves as a fundamental model for understanding users' acceptance of technology. It was initially proposed by [17], as shown in Figure 1. TAM has since been widely adopted and adapted in various research contexts [18]. In the realm of information technology and human-computer interaction, the TAM provides valuable insights into the variables influencing users' behaviour intention and acceptance [19]. Numerous studies have confirmed the validity and reliability of TAM in predicting and explaining users' behavioural intentions to accept new technology in different domains and applications [20]. By integrating TAM into research methodologies, researchers aim to provide a theoretical framework for understanding and predicting user behaviour in adopting new technologies [21].

Empirical evidence consistently supports the importance of perceived usefulness (PU) and perceived ease of use (PEOU) in determining elderly people's acceptance of smart products. The TAM identifies PU and PEOU as key determinants of technology acceptance, similar to elderly people [22]. PU is the extent to which elderly users believe that smart products will improve their daily activities and overall quality of life, significantly influencing their willingness to adopt these technologies. Studies have shown that features that enhance independence, health management, and communication are particularly valued [23]. PEOU refers to how effortless and straightforward the technology is to use, which is crucial for elderly users who may face physical and cognitive challenges. Simplified interfaces, clear instructions, and user-friendly designs enhance PEOU, making the technology more approachable and increasing acceptance among elderly people [24]. Finally, variables such as behavioural intention (BI) and actual usage (AU) are critical variables influencing elderly people's acceptance of smart products, as they reflect elderly people's willingness to engage with and eventually acceptance of technology. For instance, research indicates that elderly people who have a strong willingness to use smart health devices, such as fitness trackers, are more likely to start using these devices. The elderly people's initial motivation or desire to adopt the technology plays a significant role in whether they follow through and incorporate it into their daily lives. This finding underscores the predictive power of behavioural intentions in determining technology adoption among older adults [25].

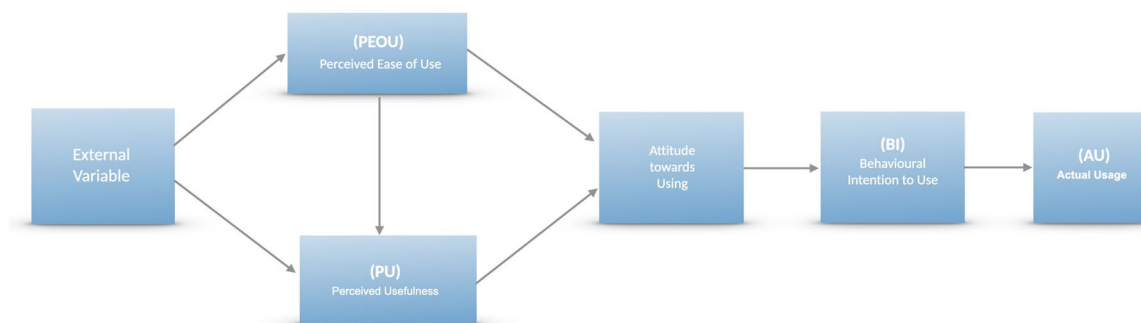


Figure 1. The original version of TAM. A diagram of the original Technology Acceptance Model (TAM) showing perceived usefulness and perceived ease of use leading to attitude towards using, which influences behavioural intention to use, resulting in actual system use.

Comparative theoretical foundations of the TAM

To establish a robust theoretical foundation, this study comparatively examined several established technology adoption models—namely the Technology Acceptance Model (TAM), Unified Theory of Acceptance and Use of Technology (UTAUT), Theory of Planned Behaviour (TPB), Diffusion of Innovation (DOI), and Matching Person and Technology (MPT)—to determine the most suitable framework for analysing ageing users' acceptance of smart products. Table 1 summarises the core constructs and contextual relevance of each model.

Among these, TAM offers the most parsimonious and empirically validated structure for investigating behavioural intention towards technology use. Its two central constructs—Perceived Usefulness (PU) and Perceived Ease of Use (PEOU)—capture cognitive evaluations that are particularly salient in ageing populations, where perceptual effort and functional benefit strongly influence acceptance [17]. The model's simplicity also allows straightforward integration of external design variables (e.g. usability, accessibility, interface simplicity), enabling practical application in product development for older adults [26].

In contrast, UTAUT extends TAM by incorporating additional constructs such as social influence and facilitating conditions. While conceptually rich, its multiple moderators (age, gender, experience, voluntariness) introduce analytical complexity and may reduce model stability in smaller, age-specific samples [27]. Similarly, the TPB provides insight into motivational and normative determinants of behaviour but lacks explicit technological constructs, limiting its explanatory power for design-oriented technology

Table 1. Key constructs and contextual applicability of technology adoption models for elderly users.

Model	Main constructs	Relevance to ageing context
Technology acceptance model (TAM)	Perceived usefulness (PU), Perceived ease of use (PEOU), attitude towards use, behavioural intention	TAM offers a parsimonious, empirically validated framework for explaining how elderly users evaluate smart technologies. Its focus on cognitive simplicity (PEOU) and functional value (PU) aligns well with ageing-related perceptual and motivational factors. The model's straightforward structure facilitates adaptation to design variables (e.g. usability, accessibility), making it ideal for developing practical design guidelines for older adults.
Unified theory of acceptance and use of technology (UTAUT)	Performance Expectancy, Effort Expectancy, Social Influence, Facilitating Conditions	UTAUT provides a more comprehensive structure but includes multiple moderating factors (e.g. gender, age, experience, voluntariness) that may complicate analysis in small elderly samples. While it captures social and environmental influences, its complexity reduces applicability in design-specific studies targeting cognitive and perceptual simplicity among ageing users.
Theory of planned behaviour (TPB)	Attitude towards behaviour, subjective norm, perceived behavioural control	TPB emphasises intentional and normative aspects of behaviour but lacks explicit technological constructs. It can explain motivational readiness among older adults but does not account for the perceived usefulness or ease of smart product interaction—both crucial for elderly technology adoption.
Diffusion of innovation (DOI)	Relative advantage, compatibility, complexity, trialability, observability	DOI focuses on innovation characteristics and adoption stages within populations. Although useful for understanding general diffusion patterns, it is less effective for capturing individual cognitive evaluations or age-specific usability perceptions. Its population-level orientation limits relevance to personalised ageing contexts.
Matching person and technology (MPT)	Person factors (abilities, motivation, psychosocial characteristics); environmental factors (social and physical support); technology factors (usability, functionality, adaptability)	MPT emphasises the fit between a person's abilities and technological features, offering valuable insight into assistive technology use. While the initial version is primarily diagnostic and supports technology selection, the follow-up version evaluates outcomes and benefits from continued use. Integrating MPT's person–technology fit perspective with behavioural models enhances design alignment for older users.

studies [28]. DOI theory contributes an innovation-centric lens but operates primarily at a population diffusion level rather than at the individual cognitive level critical for ageing-related adoption [29]. Finally, MPT emphasises the fit between individual capabilities, environmental supports, and technology characteristics, which is highly relevant to assistive and rehabilitation contexts. However, its diagnostic orientation focuses on person–technology fit rather than on behavioural intention or cognitive determinants of acceptance [30].

Collectively, this comparison demonstrates that TAM provides the optimal balance between theoretical clarity, empirical tractability, and design applicability. Its constructs directly translate into actionable design parameters—enhancing usability, simplifying interaction, and communicating usefulness—thereby supporting ageing users’ cognitive and motivational needs. Consequently, TAM serves as the most theoretically robust and practically adaptable framework for developing and validating an ageing-oriented smart product design model.

Comparative analysis of existing TAM design frameworks for elderly-oriented smart products

The TAM [17] has been widely applied to explain user acceptance of technology. Over time, extensions such as TAM2, TAM3, Unified Theory of Acceptance and Use of Technology (UTAUT), and UTAUT2 have integrated factors like social influence, facilitating conditions, and demographic moderators [31,32]. Senior-focused adaptations, such as STAM [33], further tailor these models to older adults, while more recent applications to smartphones and smart TVs demonstrate ongoing relevance [34]. Despite these variations, perceived usefulness (performance expectancy) and perceived ease of use (effort expectancy) remain the central predictors of behavioural intention [35].

However, TAM-based models mainly predict acceptance behaviour and give limited attention to design principles, interface simplicity, and usability, which are crucial for elderly users. In contrast, design frameworks such as universal or inclusive design emphasise functional simplicity, accessibility, and psychological satisfaction [36,37], but they often overlook behavioural intention.

Table 2 compares major frameworks, highlighting how the proposed framework combines acceptance constructs from TAM with ageing-oriented design principles, bridging the gap between technology adoption models and practical design needs for diabetic elderly dietary management.

Other TAM variables and elderly acceptance towards smart products

With the adoption of TAM, previous studies have explored and identified various variables influencing elderly people’s acceptance of smart products. These studies included smart products for elderly people. Among these, as elaborated before, PU and PEOU are the most important variables [22]. BI and AU are critical variables influencing elderly people’s acceptance of smart products, as they reflect the seniors’ willingness to engage with and eventually accept the technology.

First, self-efficacy (SE) is a crucial variable, reflecting the confidence elderly people have in their ability to use smart products. Higher SE leads to a greater willingness to engage with technology, as individuals feel more capable of handling potential challenges [38]. Second, perceived enjoyment (PE) also impacts acceptance. For instance, when elderly users find the use of smart products to be enjoyable and engaging, their motivation to adopt and continue using the technology increases. Enjoyable

Table 2. Comparison of existing frameworks and the proposed framework.

Framework	Main focus	Limitation for elderly	Relevance to smart product design
TAM/TAM2/TAM3	Usefulness, ease of use, social influence	Weak on product/interface design	Strong for predicting acceptance
UTAUT/UTAUT2	Performance & effort expectancy; demographics	Workplace/IT focus	Includes age but not elderly daily needs
STAM	Tailored to elderly	Lacks detailed design guidance	More relevant but narrow
Universal/Inclusive design Proposed framework	Usability, accessibility, simplicity Combines TAM & ageing-oriented design	Does not predict adoption –	Strong for elderly product design Acceptance + design guidance for diabetic elderly diet

experiences can mitigate feelings of frustration and promote sustained usage [39]. The following paragraphs comprehensively define each variable, and the hypotheses will be given.

SE is a key variable in understanding technology acceptance among elderly people. Defined by [40] as an individual's belief in his or her ability to perform specific tasks successfully, SE is crucial in the context of elderly people using smart products, as it has been demonstrated that SE positively influences both PU and PEOU, leading to higher acceptance rates of smart home technologies [41]. For example, elderly users with high SE are more likely to find smart products useful because they believe in their ability to leverage technology to improve their daily lives [42]. Compeau and Higgins emphasised that individuals with high levels of self-efficacy are more likely to recognise the advantages of technology [43]. SE also directly affects PEOU, as elderly people with high SE experience less anxiety and find it easier to learn and use new technologies. This gives rise to the following hypotheses:

H1a. SE has a positive influence on PU.

H1b. SE has a positive influence on BI.

Perceived enjoyment (PE) is an essential variable in understanding technology acceptance, particularly among elderly people. PE refers to the extent to which the use of technology is perceived to be enjoyable, regardless of any performance consequences. Empirical studies reinforce the positive impact of PE on technology acceptance among elderly people [17] highlighted PE as an intrinsic motivation influencing technology acceptance, suggesting that when users find technology enjoyable, they are more likely to engage with it [44, 45] reported that PE significantly influences both PU and PEOU, leading to higher acceptance rates [45]. For instance, PE complements these determinants by adding an emotional and intrinsic motivational aspect to technology use: when elderly users find technology enjoyable, they are more inclined to perceive it as useful. Enjoyment enhances their overall experience, making the technology more beneficial and valuable in their daily lives [31]. Therefore, the following hypotheses were formulated:

H2. PE has a positive influence on BI.

Smart product design variables and elderly acceptance

In addition, with respect to key smart product design variables, three crucial factors need to be considered for ageing design, namely, interface design (ID), appearance design (AD) and function design (FD). First, ID and AD are vital in shaping the user experience, since a well-designed interface that is easy to navigate can reduce cognitive load and make interactions more pleasant [46]. Similarly, aesthetically pleasing products can attract elderly users, who might be more inclined to use technology that looks appealing [47]. Additionally, FD pertains to the features and capabilities of smart products, for example, products that offer relevant and useful functions tailored to the needs of elderly people. The following paragraphs will comprehensively review and conclude the definition of each variable, and the hypotheses will be given after that.

ID is a critical component of the acceptance of technology, especially among elderly users. ID encompasses the layout, visual aesthetics, and usability of a technological interface. Good interface design aims to make technology accessible, intuitive, and user-friendly, which is crucial for elderly people who may have varying levels of tech-savviness and potential physical limitations such as impaired vision or reduced dexterity. Heatherly highlighted that interface design features tailored to the needs of elderly users can significantly enhance PEOU, leading to higher acceptance rates of smart products. For example, a well-designed interface can enhance the perceived usefulness of a technology by making its features more accessible and easier to understand. If elderly users find the interface intuitive and straightforward, they are more likely to recognise the practical benefits of the smart product [32]. ID directly impacts PEOU; for instance, a user-friendly interface reduces the cognitive load required to interact with technology, making it less daunting and more manageable. This is particularly important for elderly users who may be less familiar with digital interfaces. Simplified navigation, clear icons, and responsive design elements can significantly improve ease of use [48].

Effective ID can lead to greater adoption of technology, thereby enhancing the quality of life for elderly people through increased independence and better access to digital resources. Two hypotheses are given below:

H3a. ID has a positive influence on PU.

H3b. ID has a positive influence on PEOU.

AD refers to the aesthetic aspects of a product, including its form, colour, texture, and overall visual appeal. A well-designed appearance can enhance the user experience by making the product more attractive and engaging, which can be particularly important for older adults who may be apprehensive about adopting new technologies. A study by Karapanos, Hassenzahl, and Martens indicated that attractive AD can enhance both PU and PEOU by creating positive initial impressions and fostering a sense of ease and comfort with the product. For instance, attractive AD can enhance the perceived usefulness of a technology by making it more appealing and desirable. When elderly users find a product visually pleasing, they are more likely to perceive it as beneficial and worthwhile. This positive perception can increase their willingness to use a product [49]. Moreover, AD can also influence PEOU. A well-designed product that looks modern and sophisticated may be perceived as easier to use because it suggests that the technology is up-to-date and user-friendly. Conversely, products that appear outdated or overly complex may deter use by implying difficulty [50]. Effective AD can lead to greater acceptance of technology, improving the quality of life for elderly people by making technology more accessible and enjoyable to use.

H4a. AD has a positive influence on PU.

H4b. AD has a positive influence on PEOU.

FD refers to the specific features and capabilities that a product offers to its users. In the context of smart products for elderly people, FD encompasses the functionalities that address their unique needs, such as health monitoring, emergency assistance, and ease of communication. Effective FD ensures that the technology provides tangible benefits and meets the practical requirements of elderly users. In a study by Chen and Chan, well-designed functionalities significantly increased both PU and PEOU, leading to higher acceptance rates of smart technologies among elderly users. On the one hand, the specific functionalities of a smart product can greatly enhance its perceived usefulness. When elderly people find that a product has features that significantly improve their daily lives, such as fall detection or medication reminders, they are more likely to perceive it as beneficial [32]. This perception of usefulness is crucial for technology acceptance. On the other hand, FD also impacts PEOU. Features designed with the elderly in mind, such as voice commands, large buttons, and simplified navigation, make the product easier to use. When smart products are tailored to the physical and cognitive capabilities of elderly users, they are more likely to find the technology approachable and less intimidating [37]. Effective FD can lead to greater acceptance of smart products, enhancing the quality of life for elderly people by providing practical and supportive technological solutions. Related hypotheses are listed below:

H5a. FD has a positive influence on PU.

H5b. FD has a positive influence on PEOU.

TAM variables and elderly acceptance

The following sections describe and justify all of the predicted hypotheses, considering the outcomes of previous literature. The following sections will elaborate on those key variables in this TAM conceptual framework.

The acceptance of smart products by elderly people is influenced by PU, PEOU, BI, AU, SE, PE, ID, AD and FD. These variables guide the development of user-friendly technologies that enhance elderly people's quality of life. It was stated in the TAM and other relevant studies that these variables have a significant impact on the ratio of BI to AU.

Previous studies demonstrated that PEOU has a significant impact on PU. Similarly, PEOU has been shown to positively influence PU, and there is evidence of a positive direct or indirect correlation

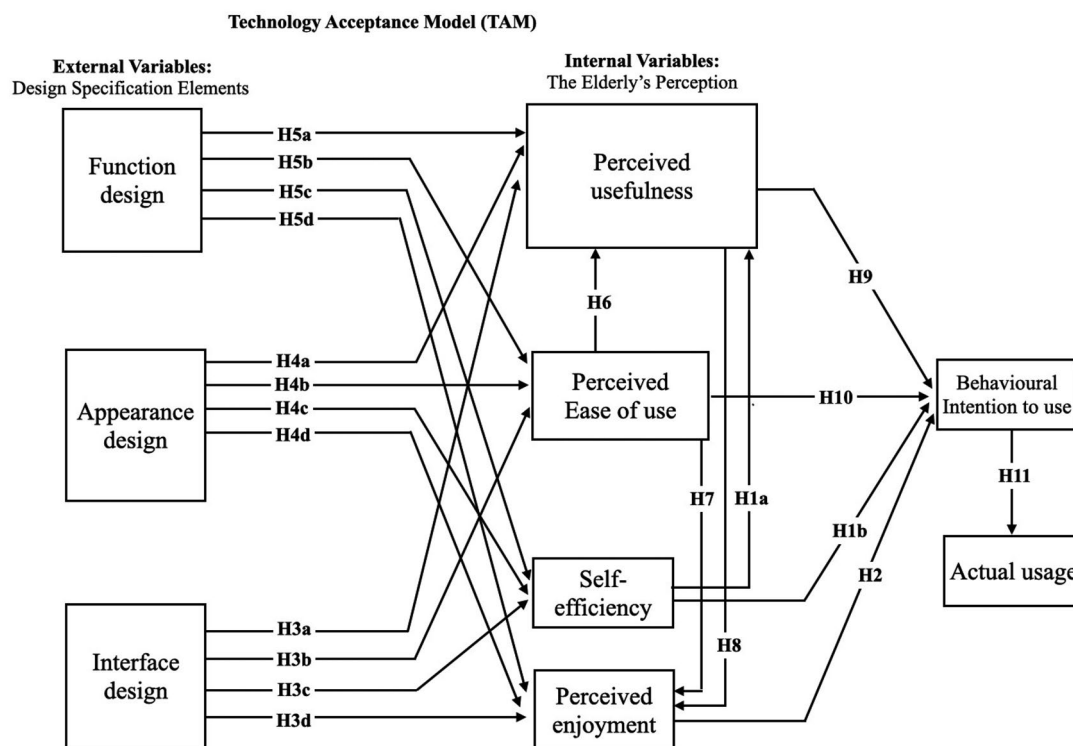


Figure 2. The hypothesised relations among the variables. A detailed diagram of the extended TAM, showing external variables (FD, AD, ID) influencing internal variables (PU, PEOU, SE, PE), which in turn affect BI to AU. Illustrating hypothesised relationships (H1-H11) among these variables, represented by arrows connecting the elements.

between PEOU and BI in relation to the use of smart products. PU exerts a direct or indirect influence on the willingness of the elderly population to actual usage (AU) of smart products. PU is significantly and positively correlated with both BI and PE of smart products among the elderly population. Consequently, this study proposes the following hypotheses. There is a significant positive correlation between BI, AU, PE, PU and PEOU. Therefore, [Figure 2](#) elaborates the hypothesised relations among the variables:

- H6.** PEOU has a positive influence on PU.
- H7.** PEOU has a positive influence on PE.
- H8.** PU has a positive influence on PE.
- H9.** PU has a positive influence on the elderly's BI.
- H10.** PEOU has a positive influence on the elderly's BI.
- H11.** BI has a positive influence on AU.

Methodology

This study employed a mixed-method approach to identify key variables influencing diabetic elderly individuals' acceptance of smart products and to develop an ageing-oriented design framework based on the TAM. The study received approval from the Ethics Committee for Research Involving Human Subjects at Universiti Putra Malaysia (JKEUPM) under reference number JKEUPM-2023-1320 (see supporting document). The pilot study begins with the literature review and questionnaire in Guangdong province China, then adopted expert review to validate this research outcomes. Conducting a literature review before the questionnaire ensures that the themes and variables identified can inform the content and structure of the questionnaire, making it more focused and contextually relevant. The questionnaire will quantitatively assess the key variables identified in literature review, allowing the study to generalise the findings to a broader population.

The research design process comprised three phases: (1) Conceptualising the framework through literature review and identification of key variables; (2) Conducting a questionnaire to diabetic elderly group to identify and examine relationships among variables using statistical analysis; and (3) Developing the final framework and validating it through expert review to ensure its applicability and robustness. The subsequent sections provide detailed explanations of the research design and procedures for each phase.

Questionnaire participants

A Chinese version questionnaire was designed to validate the hypothesised relationships among the variables (also provide English version in supporting documents). Written informed consent was obtained from all participants (these consent contents were shown in the first page of questionnaire, the participants were agreed to proceed), ensuring confidentiality and voluntary participation. A clear definition and examples of smart products were provided at the beginning of the questionnaire, this ensured participants understood the term consistently before answering. Once the questionnaire was prepared, it was distributed among elderly people in Guangdong China. The respondents were screened according to the following inclusion criteria (a. Elderly people aged 60years and above with diabetes; b. Elderly people who lived in Guangdong province; c. Elderly people who had experience in using smart products); exclusion criteria including: (a. Not lived in Guangdong province; b. Not elderly people who are younger than 60years old; c. Not familiar with smart products). To collect information about the preferences of elderly people, this questionnaire is divided into two sections. Section A: Demography; Section B: Attitudes towards smart products.

The study used a convenience sampling approach due to accessibility constraints and the target demographic's technological literacy. However, efforts were made to reach participants across different urban and semi-urban areas in Guangdong through local elderly community centres, nursing homes, and WeChat groups. The sample size for the questionnaire ($n=303$) was determined using the Raosoft sample size calculator, ensuring a 95% confidence level and a 5% margin of error, appropriate for the estimated elderly population in the region, which is a widely used tool in social science research.

Pilot study

The pilot testing was conducted at Anren Nursing Home, Chenzhou City, Hunan Province, China, after the initial development of the questionnaires (Part A and Part B). The pilot study aimed to assess the clarity, flow, and comprehensibility of the questionnaires, as well as the suitability of their length and structure for elderly participants. A total of ten individuals aged 60 and above took part in both rounds. The first pilot test for Phase II (Part A) was carried out in early April 2023, and the second test for Phase II (Part B) in early May 2023, each involving ten respondents.

Both parts were completed within one week, with three days allocated to Part A and four days to Part B. Participant feedback was carefully recorded, highlighting issues such as unclear instructions, difficulty with certain questions, fatigue from questionnaire length, and time taken to complete. Revisions were made accordingly: some questions were simplified, technical terms were replaced with more familiar wording, and the definition of "smart products" was added at the start. The Likert scale was reduced from seven to five points for ease of response, and terms like "IoT" and "AI" were simplified to "smart," with adjustments also made in the Chinese version.

Questionnaire procedure

The goal of this questionnaire is to use feedback data to investigate the critical variables in determining the elderly's acceptance. The questionnaire adopted a 5-point Likert scale for elderly people that ranged from 1 (strongly disagree) to 5 (strongly agree). The scale consisted of nine constructs in the

Table 3. Questionnaire constructs and sample items.

Constructs	Sample scale item	Number of items
SE	*I believe I can adeptly operate and manage smart products independently. *I can learn how to use smart products. *Under the guidance of others, I can proficiently operate and utilise smart products.	3
PE	*I find using smart products to be intriguing. *I experience a sense of happiness when using smart products. *Using smart products is an enjoyable experience.	3
ID	*My primary concern revolves around the interactivity of smart products. *I desire a straightforward and user-friendly interface for smart products. *I prefer a smart, simple, and easily understandable product interface.	3
AD	*I prefer smart products to exhibit a steady style. *The colour of smart products are both simple and bright. *The materials used for smart products are comfortable.	3
FD	*My primary concern lies in the functionality of smart products. *I aim to utilise the majority of functions available in smart products. *A well-designed functional system inclines me towards using smart products.	3
PU	*Smart products can enhance the efficiency of my life. *Smart products can significantly enhance the convenience of my life. *Smart products can effectively meet my needs.	3
PEOU	*Smart products are designed to provide ease of use. *Smart products are designed to facilitate easy usage. *Smart products are designed to easy learning.	3
BI	*I am willing to use smart products. *In the future, I envision myself using smart products. *I am genuinely interested in using a smart product.	3
AU	*I am currently using or in the process of learning to use a smart product. *In the future, I intend to make an effort to use smart products. *Mastering how to use smart products is of utmost importance.	3

questionnaire that developed from previous research and the literature review (see supporting documents). The instrument comprised two sections: Section A: Demographic information (age, gender, education, income, living arrangement, and health status); Section B: Attitudes towards smart products, measured across nine constructs (Self-efficacy, Perceived Enjoyment, Interface Design, Aesthetic Design, Functional Design, Perceived Usefulness, Perceived Ease of Use, Behavioural Intention, and Actual Use). Table 3 lists each construct and sample item.

From Jan 2 to March 7, 2024, the questionnaire was distributed to elderly people who were 60 years old and above met the criteria in Guangdong Province through Wenjuanxing software online (<https://www.wjx.cn>) with an amount of 420 respondents, and 303 valid responses were received, the questionnaire was distributed online (WeChat groups and email). A brief explanation of “smart products” and examples (e.g. smartwatches, health-monitoring devices, voice assistants) were presented at the beginning of the survey to ensure consistent understanding. Participants provided informed consent electronically before proceeding. These responses constituted sample sizes ($n=303$) and were used for the validity analysis first. After obtaining the findings of validity analysis, another independent set of data was collected for confirmatory factor analysis. A total of 303 valid responses were received for these questionnaires (see supporting documents). The descriptive statistics of the participants’ demographic data are listed in Table 4. Participants were elderly individuals aged 60 years and above. The age distribution was as follows: 60–65 years (24.4%), 66–70 years (25.1%), 71–74 years (22.4%), and 75 years or older (28.1%). A total of 303 valid responses were analysed (response rate = 72.1%). The gender distribution was 53.8% female and 46.2% male. Educational backgrounds ranged from no formal schooling (11.2%) to postgraduate qualifications (6.9%). Regarding income, 50.2% earned between 3,000–5,000 RMB monthly, and 13.9% earned above 8,000 RMB. Most respondents self-identified as being in stable health conditions, with diabetes as a common chronic illness among the sample, aligning with the study’s focus on diabetic elderly individuals. To ensure relevance, all respondents were required to have prior experience using at least one type of smart product, such as a smartphone, smart blood glucose monitor, or wearable health tracker.

Data analysis

The data analysis consisted of four stages: validity analysis, reliability analysis, confirmatory factor analysis (CFA), and structural equation modelling (SEM). Validity analysis and reliability analysis of the scale were

Table 4. Results of participants' demographic information.

Questions	Options	Frequency	Per (%)	Total per (%)
1) Are you over 60years old?	Yes	303	100.00	100.00
2) Do you have prior experience using smart products?	Yes	303	100.00	100.00
3) What is your gender?	Female	163	53.80	53.80
	Male	140	46.20	100.00
4) What is your age?	60-65 years	74	24.42	24.42
	66-70 years	76	25.08	49.50
	71-74 years	68	22.44	71.95
	75 years and above	85	28.05	100.00
5) What is the highest degree or level of school you have completed?	No schooling completed	34	11.22	11.22
	Primary school graduate	87	28.71	39.93
	High school graduate	86	28.38	68.32
	Bachelor's degree	75	24.75	93.07
	Master's degree	11	3.63	96.70
6) What is your living status?	Doctoral degree	10	3.30	100.00
	Living alone	107	35.31	35.31
	Living with spouse	109	35.97	71.29
	Living with a child (or children)	41	13.53	84.82
	Living with others	46	15.18	100.00
7) What is your income level?	3000RMB below	34	11.22	11.22
	3000–5000 RMB	118	38.94	50.17
	5000–8000 RMB	109	35.97	86.14
	8000 RMB above	42	13.86	100.00
Sum		303	100.0	100.0

first conducted with SPSS26.0, and CFA and SEM were sequentially conducted with SPSS. All 303 samples were used for validity analysis, CFA, reliability analysis and SEM.

In the validity analysis process, factor analysis for information enrichment studies by first analysing the suitability of the study data for factor analysis, and components were extracted with KMO eigenvalues greater than 0.6. Items Bartlett with value (<0.05) were validated [51]. In the reliability analysis of the scale, the internal consistency coefficients' Cronbach's α values were calculated, where the whole scale and all constructs needed to be higher than 0.8 [52].

In the CFA and SEM, the standards recommended by Hair et al [53] were adopted. Accordingly, the indices χ^2/df (<5), root mean square error of approximation (RMSEA) (<0.10), comparative fit index (CFI) (>0.90), and Tucker-Lewis index (TLI) (>0.90) were used to assess the degree of model fit. Then the average variance extracted (AVE) (>0.5) and construct reliability (CR) (>0.7) were calculated using factor loadings (λ) to check the convergent validity of the scale. The square root values of the AVEs of the components were compared with the correlations between components to check the discriminant validity of the scale. The correlations between all factors were tested for significance before SEM [54].

Expert review validation procedure

The objective of the expert review was to validate the effectiveness and practicality of the framework, ensuring that products designed using it enhance technological acceptance and usability, thereby benefiting ageing-oriented designers, diabetic researchers, government staff, and healthcare-related researchers.

Expert selection and information

Experts were selected based on their knowledge and experience in fields related to ageing, healthcare (nutrition, dietitian, diabetes), community, government background, smart product design, and human-computer interaction. The selection process ensured a multidisciplinary approach, with experts representing various fields to provide a well-rounded evaluation of the framework. Table 5 listed the categories and criteria selection of experts.

Table 5. Categories and criteria selection of experts.

	Criteria of experts selection
1. Industrial design researchers	Senior product designers with experience in UX/ UI design and industrial design.
2. Healthcare field specialists	Healthcare researchers (must have Ph.D. degree or professor in certain field) specialising in nutrition, dietation and related doctor.
3. Sector of community, community elderly, government staff	Elderly leader of community and dean of certain government department.
4. Academy researchers	Industrial design researcher (must have Ph.D. degree) focused on gerontology, human-computer interaction, Technology Acceptance Model or industrial design related fields.

Table 6. Respondent background for expert validation.

Expert	Category	Years of experience	Area of expertise
1	Industrial design research	9	Industrial design (UI)
2	Industrial design research	5	Industrial design (Product)
3	Healthcare field specialists	31	Healthcare, diabetes
4	Healthcare field specialists	8	Healthcare and medicine
5	Healthcare field specialists	5	Dietetic care, primary care
6	Healthcare field specialists	6	Nutrition, primary care
7	Healthcare field specialists	9	Dietitian, primary care
8	Healthcare field specialists	13	Dietitian, nutrition
9	Sector of community, community elderly, government staff	12	Ageing community management
10	Sector of community, community elderly, government staff	32	Children healthcare
11	Sector of community, community elderly, government staff	12	Health and hygiene
12	Academy researchers	10	UX and industrial design PhD
13	Academy researchers	10	Industrial design, green design

Based on the selection criteria, four comprehensive expert categories were included in the framework validation process. 13 experts were confirmed and invited to be framework validation experts, including 2 designers (1 UI designer, 1 industrial designer), 6 healthcare related doctors and experts (1 public hospital dean, 1 healthcare and ageing associate professor, 1 dietetic doctor, 2 nutrition doctor and 1 diabetes doctor), 3 ageing community staff (1 leader of ageing community, 1 community elderly and 1 related government staff), 2 academy researchers (1 PhD researcher in industrial design, 1 PhD researcher in user experience design). The selected experts background is listed in [Table 6](#). Before the review sessions, experts were emailed with an expert review form, which provided with appointment form, consent form, evaluation form and an overview of the proposed framework, and relevant research findings (see supporting document).

Conduct expert review procedure

Thirteen experts were invited *via* email, communication software, or in person (see supporting document), with invitations written in Chinese or English. Upon agreeing to participate, they received the review forms, framework documents, and consent forms. Experts independently reviewed the materials, completed the validation forms, and returned signed scanned copies (PDF/Word) *via* email after verifying accuracy. The researcher compiled all feedback into a report summarising findings and suggested revisions for the framework. The review process spanned two weeks (16–30 March 2025). If feasible, a face-to-face session will be held, with several hospital doctors and specialists already agreeing to participate.

The framework evaluation checklist was used by 13 experts from related fields to assess the proposed framework for diabetic elderly product design. Experts rated aspects such as focus, usability, adoption, components, applicability, and innovation on a 5-point scale, and their feedback, including suggestions and recommendations (see supporting document), was incorporated to strengthen the framework. This process provided comprehensive insights to refine the framework for practical application.

Results

Validity and reliability

The validity analysis results showed good validity of the scale. The KMO of 0.825 is greater than 0.6, thus satisfying the prerequisite requirements for factor analysis. Consequently, the data may be used for a factor analysis study. Furthermore, the data passed Bartlett’s test of sphericity ($p < 0.05$), indicating that the research data are suitable for factor analysis (see Table 7).

To further verify the structural validity of the scale, CFA was carried out. The model fit indices of χ^2/df were 1.225 (< 3), RMSEA was 0.029 (< 0.10), CFI was 0.978 (> 0.90), and TLI was 0.973 (> 0.90), indicating that the fit for the items of the scale was acceptable as shown in Table 8.

As shown in Table 5, all standardised factor loadings were in a good range of 0.727 to 0.893. The AVE values were higher than 0.5, and the CR values were higher than 0.7, indicating good convergent validity. All the square root values of the AVE of each component were higher than the correlations between each component and the other components (see Table 9), indicating good discriminant validity.

Table 7. Means, standard deviations, factor loadings (λ), AVEs, and construct reliability.

Variables	Measurements	Non-standard load				Standard load			
		factor	standard error	CR value	p	factor	AVE value	CR value	
PU	PU1	1	–	–	–	0.784	0.572	0.8	
	PU2	0.804	0.07	11.506	0	0.737			
	PU3	0.802	0.069	11.616	0	0.747			
PEOU	PEOU1	1	–	–	–	0.807	0.561	0.792	
	PEOU2	0.766	0.066	11.626	0	0.76			
	PEOU3	0.646	0.06	10.682	0	0.673			
PE	PE1	1	–	–	–	0.866	0.63	0.835	
	PE2	0.712	0.052	13.819	0	0.782			
	PE3	0.656	0.051	12.93	0	0.727			
SE	SE1	1	–	–	–	0.877	0.602	0.818	
	SE2	0.721	0.058	12.442	0	0.759			
	SE3	0.628	0.055	11.41	0	0.679			
BI	BI1	1	–	–	–	0.809	0.558	0.79	
	BI2	0.753	0.062	12.115	0	0.761			
	BI3	0.645	0.06	10.795	0	0.663			
AC	AU1	1	–	–	–	0.893	0.64	0.841	
	AU2	0.649	0.051	12.768	0	0.722			
	AU3	0.695	0.051	13.551	0	0.775			
FD	FD1	1	–	–	–	0.873	0.639	0.841	
	FD2	0.673	0.051	13.234	0	0.735			
	FD3	0.747	0.053	14.048	0	0.784			
AD	AD1	1	–	–	–	0.88	0.653	0.849	
	AD2	0.741	0.051	14.417	0	0.801			
	AD3	0.66	0.049	13.403	0	0.737			
ID	ID1	1	–	–	–	0.751	0.552	0.787	
	ID2	0.946	0.088	10.789	0	0.782			
		0.836	0.081	10.296	0	0.694			

Note: A ‘–’ indicates that the item is a reference item.

Table 8. Model fit indicators.

I	χ^2	df	p	χ^2/df	GFI	RMSEA	CFI	NFI	TLI	AGFI	IFI
Criterion values	–	–	> 0.05	< 3	> 0.9	< 0.10	> 0.9	> 0.9	> 0.9	> 0.9	> 0.9
Values	361.553	288	0.002	1.255	0.921	0.029	0.978	0.902	0.973	0.896	0.978

Table 9. Correlations between components and AVE of the components.

	PU	PEOU	PE	SE	BI	AU	FD	AD	ID
PU	0.756								
PEOU	0.371	0.749							
PE	0.348	0.362	0.794						
SE	0.297	0.263	0.255	0.776					
BI	0.375	0.375	0.366	0.317	0.747				
AU	0.126	0.247	0.168	0.171	0.293	0.800			
FD	0.314	0.297	0.364	0.308	0.341	0.244	0.799		
AD	0.247	0.202	0.260	0.145	0.327	0.104	0.182	0.808	
ID	0.278	0.241	0.242	0.203	0.324	0.135	0.237	0.069	0.743

Note: The diagonal figures are AVE square root values.

Table 10. Reliability analysis.

Variables	Measurements	Correlation of corrected entries with totals	Clone bach after deletion alpha	Clone bach alpha
PU	PU1	0.684	0.681	0.797
	PU2	0.624	0.741	
	PU3	0.627	0.739	
PEOU	PEOU1	0.69	0.637	0.783
	PEOU2	0.64	0.689	
	PEOU3	0.562	0.768	
PE	PE1	0.757	0.693	0.826
	PE2	0.684	0.763	
	PE3	0.64	0.803	
SE	SE1	0.744	0.644	0.807
	SE2	0.655	0.739	
	SE3	0.592	0.799	
BI	BI1	0.713	0.602	0.781
	BI2	0.604	0.723	
	BI3	0.571	0.756	
AC	AU1	0.774	0.688	0.831
	AU2	0.644	0.812	
	AU3	0.684	0.777	
FD	FD1	0.77	0.697	0.833
	FD2	0.656	0.807	
	FD3	0.681	0.783	
AD	AD1	0.772	0.724	0.842
	AD2	0.706	0.783	
	AD3	0.67	0.817	
ID	ID1	0.639	0.695	0.785
	ID2	0.643	0.69	
	ID3	0.595	0.739	

The internal consistency coefficient test showed good reliability of the scale. All the construct reliabilities were higher than 0.8, indicating good reliability as shown in Table 10. Consequently, the data results of this paper passed the reliability test.

SEM for hypothesis testing

The model fit indices of the structural equation model (SEM) were good as listed in Table 4. The χ^2/df was 1.255 (< 3.0), the RMSEA was 0.029 (< 0.10), the CFI was 0.978 (> 0.90), and the TLI was 0.973 (> 0.90), indicating a good fit of the structural equation model. The verification of the path coefficients of the structural equation model is shown in Figure 3.

With the final goal of examining the proposed hypotheses, the relationships that the theoretical constructs for the structural model have with each other were assessed *via* a structural equation model that had SEM-PLS with maximum likelihood estimation. The validated results show that the hypothesised paths of SE, PE, PU, and PEOU all have a positive influence on BI. Hypotheses H1b, H10, H9 and H2 were supported in this research. Consequently, BI directly influences AU, therefore influencing final acceptance.

The external variables included FD, AD and ID. The hypothesised paths of FD to PU, PEOU, SE and PE were significant. The hypothesised paths of AD to PU, PEOU and PE were significantly correlated, but the path of AD to SE was not significant ($p > 0.05$), which means that AD and SE did not have direct significant predictive power on BI. H4c therefore was not supported. The hypothesised paths of ID to PU, PEOU and SE tested significant correlations, but the path of ID to PE did not reach a significant degree ($p > 0.05$), which means that ID and PE did not have direct significant predictive power on BI. H3B therefore was not supported. A comprehensive summary of the hypotheses testing results is shown in Table 8.

Framework development

The development of the framework is based on insights gathered from the previous research phases, including literature review, conceptual framework and questionnaire results. This framework integrates key variables from TAM and produce design, customised for the diabetic elderly, and incorporates specific design principles aimed at addressing their needs, such as ease of use, perceived usefulness. The

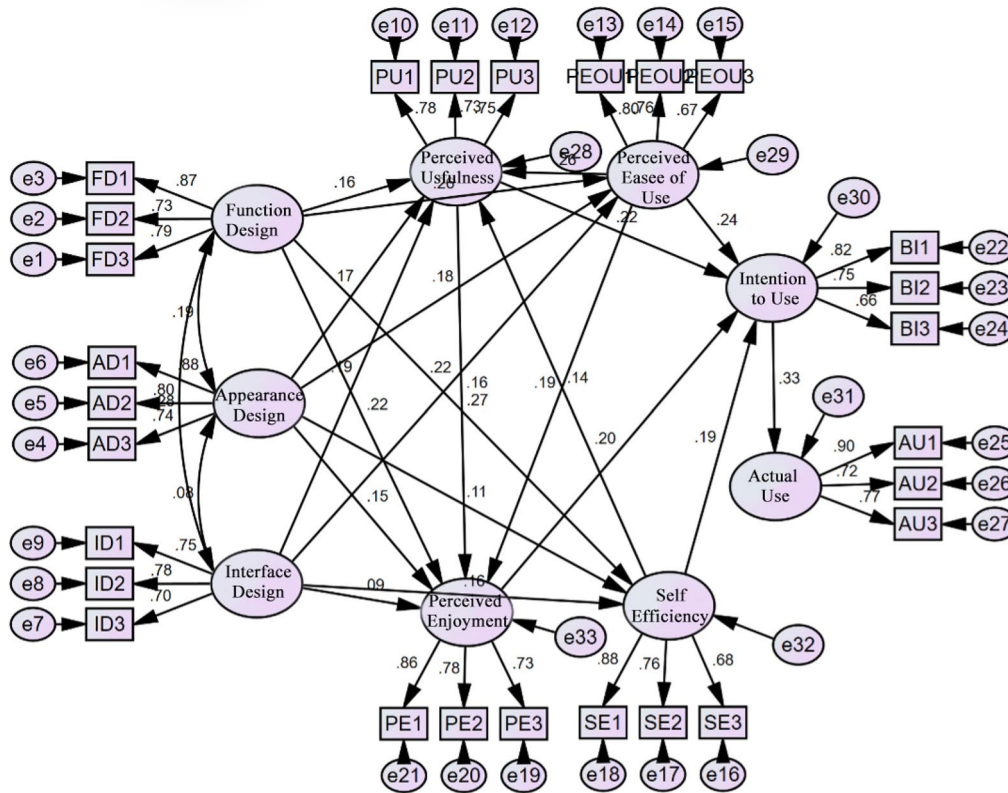


Figure 3. The Path coefficients of the structural equation model. A diagram showing the path coefficients between design elements (FD, AD, ID) and internal variables (PU, PEOU, PE, SE), leading to Intention to Use and Actual Use. Path coefficients (numbers on the arrows) indicate the strength of the relationships, with loadings on indicators shown next to each variable.

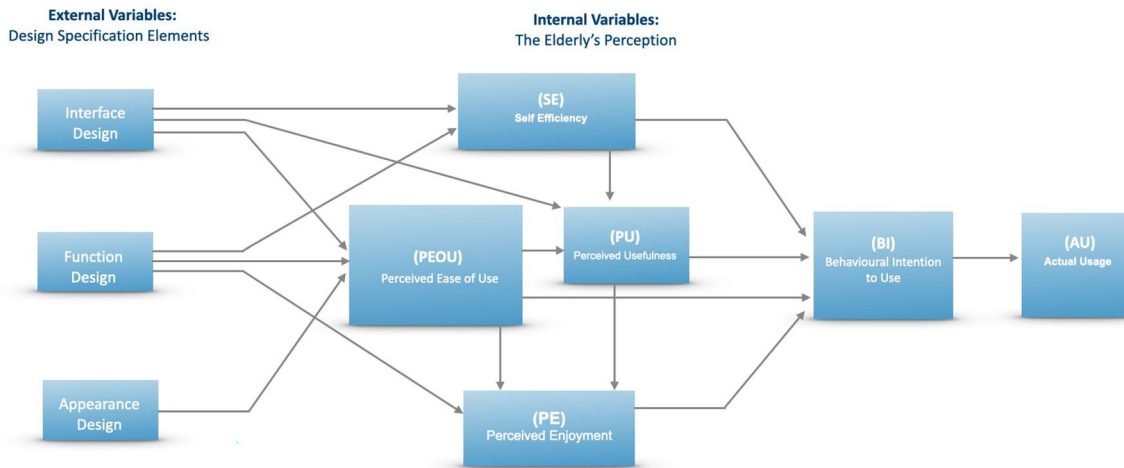


Figure 4. The proposed smart product design framework for the diabetic elderly based on TAM. The framework includes external variables (ID, FD, AD) influencing internal variables (SE, PU, PEOU, PE), which in turn affect Behavioural Intention to Use and Actual Usage of the product.

flow of developing the framework, illustrated in Figure 5, outlines the relationships between interface design, function design, and appearance design, and their significant influence on PEOU, PU, and SE. Building upon these variables, the proposed framework design flow suggests targeted design directions: Firstly, interface design is the key variable that influences PEOU, PU, and SE. It emphasises user-friendly interfaces, focusing on easy navigation, accessible features, and supportive feedback mechanisms to

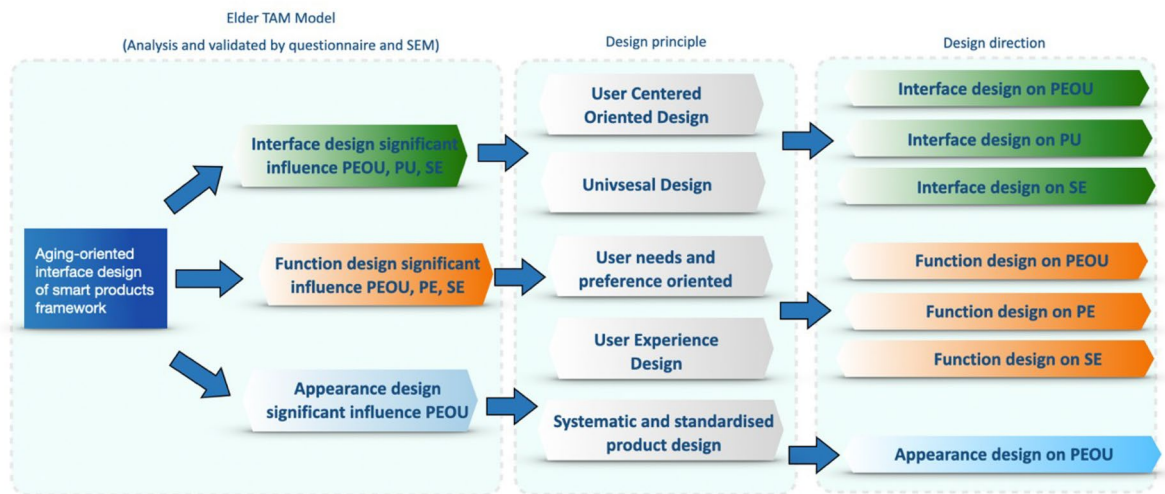


Figure 5. Design Flow of Ageing-oriented Smart Products Design Framework. Figure flowchart illustrating the ageing-oriented smart product design framework. The left section shows three design elements—interface, function, and appearance—each with their significant influences on acceptance variables (PEOU, PU, PE, SE). The middle section presents key design principles: user-centered oriented design, universal design, user needs and preference oriented, user experience design, and systematic/standardised product design. The right section highlights specific design directions, linking each principle to targeted interface, function, or appearance design tasks focused on PEOU, PU, PE, and SE.

accommodate the needs of elderly users. Following the important variable of function design, which influences PEOU, PU, and SE. It prioritises core functionalities that address practical needs, allowing for efficient and intuitive interaction, while incorporating flexible options to enhance usability. Lastly, appearance design variable which primarily influences PEOU. This aspect involves aesthetic considerations that enhance the visual appeal, along with ergonomic factors to ensure physical comfort and ease of use.

The ageing-oriented smart products design framework is a structured approach to creating products tailored to improve the acceptance of elderly individuals with diabetes. The framework begins with the Product Design phase, where the design requirements are established, ensuring that the product is developed with a clear understanding of the users' needs and challenges. This phase ensures that the design process is user-centered, particularly addressing the requirements of diabetic elderly users and improving their acceptance. The design process focuses on two main components based on the investigation results: Function design, appearance design and interface design.

A unique element of this framework is the integration of TAM variables. This model assesses the users' attitudes towards the product by focusing on key variables including: PEOU, PU, PE and SE. These variables are crucial for understanding whether elderly users will accept and feel confident using the smart product. PEOU evaluates how easily users can operate the product, while PU assesses how well the product addresses their needs. SE measures the users' belief in their ability to successfully use the product. Together, these variables ensure that the product is not only functional but also likely to be adopted by the target user group. The proposed ageing-oriented interface design of smart products framework is presented in Figure 6.

Framework validation

The expert review validation process employed a qualitative thematic analysis to evaluate the proposed framework for its suitability in guiding the design and development of smart products for elderly diabetic users. The expert evaluation results, as recorded in supporting document [5], were analysed to uncover key insights and themes that provide a deeper understanding of the framework's effectiveness, strengths, and areas for improvement.

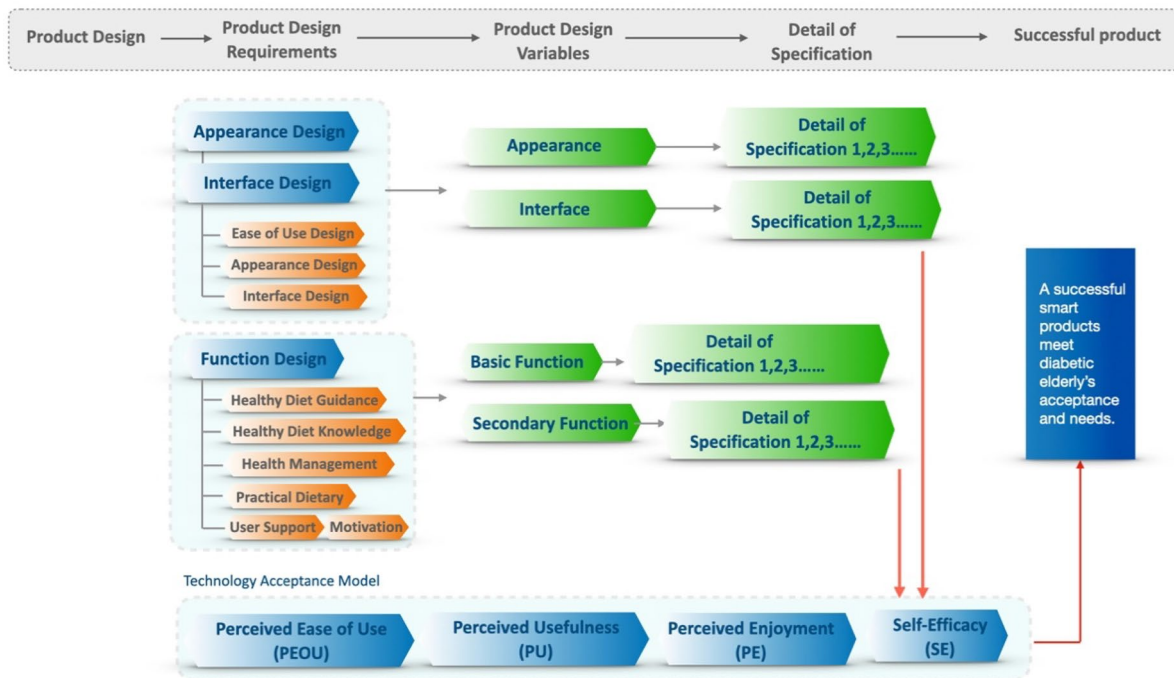


Figure 6. Proposed ageing-oriented interface design of smart products framework. Flowchart of the proposed ageing-oriented interface design framework. It links appearance, interface, and function design—covering ease of use, health guidance, and user support—to product design variables (appearance, interface, basic and secondary functions) and detailed specifications. At the base, Technology Acceptance Model factors—Perceived Ease of Use, Perceived Usefulness, Perceived Enjoyment, and Self-Efficacy—feed into specifications, leading to a smart product that meets diabetic elderly users’ needs and acceptance.

Results and analysis of the expert review validation

The analysis of these results reveals a strong consensus across all categories, emphasising the framework’s relevance, usability, and effectiveness in real-world applications. The following sections provide a detailed analysis of expert feedback on the basis of the evaluation criteria checklist results.

First, regarding to the “Focus” evaluation item, which reflects that 10 experts agreed that the framework is well-suited to address the specific challenges faced by elderly diabetic users, whereas only 1 expert provided a middle score. This strong consensus shows that the framework’s objectives resonate with the needs of the target population, ensuring that the resulting products are both functional and tailored to real-world conditions.

Second, with respect to the “usability and adoption” evaluation item, 9 out of the 13 experts rated the framework positively to enhance usability and acceptance. Expert feedback emphasised the importance of user-centered design, which helps improve the adoption of smart products by elderly users. Expert 2, who stated, “The framework can enhance the acceptance of smart products among the target population by improving usability and overall efficacy.” This finding underscores that the usability and accessibility of the framework are central to its success.

Third, the “Components” evaluation highlighted the framework’s focus on creating visually appealing products. Experts emphasised the importance of larger icons, colour contrast, and intuitive functionalities for elderly users with visual or cognitive impairments. Expert 1 remarked, “The framework ensures that the smart product’s appearance is aesthetically pleasing, with clear, approachable visuals, color, and larger icons to improve visibility.” These features are crucial to ensuring the products are user-friendly, functional, and easily navigable.

Then, the “Innovation” evaluation item emphasised the cross-disciplinary collaboration fostered by the framework, which incorporates industrial design, engineering, and computer science to create innovative design principles. Experts such as expert 13 commented, “The framework introduces new and innovative design principles for smart products (prototypes) targeting diabetic elderly users.” This approach

introduces cutting-edge solutions for the elderly diabetic population, validating the framework's potential to introduce new and practical innovations.

Finally, according to "Practicality" evaluation item, the framework's practicality was another area that received strong approval from the expert reviewers. 10 out of 13 experts rated the framework highly for its ability to meet the needs of the target population and its ease of implementation. Experts noted that the framework can be easily understood and implemented in the development of prototypes, ensuring its real-world applicability. Expert 5 stated, "The framework is easy to comprehend and effectively implement in the development of smart product prototypes." This feedback indicates that the framework is not only theoretically sound but also practically viable, confirming its potential for real-world adoption.

The expert validation analysis, as detailed through the evaluation checklist, affirms that the proposed framework is both relevant and effective in guiding the design of smart products for elderly diabetic users. The framework's strong alignment with real-world needs, its focus on usability and accessibility, its integration of innovative design principles, and its cross-disciplinary approach all contribute to its effectiveness. However, feedback from the experts suggests that certain improvements, particularly in terms of clarification of technical jargon and enhancing readability for elderly users, could further strengthen the framework's practical application.

Discussion

To examine elderly people's intention to accept and use smart products, this paper investigated smart product design variables associated with elderly people's perceptions of TAM. A total of 19 hypotheses were supported, while two were not. Hence, the hypothesised framework is generally supported. The findings of this study are further discussed.

This study used CFA to establish a valid and reliable scale to measure elderly people's perceptions of smart products, TAM variables, and behavioural intention to actual usage smart products. For this scale, we developed items about elderly people's preference and perception towards product design and TAM variables (see Appendix questionnaire and Table 3), which are innovative in designing smart products for the ageing field and can be used in future studies. This questionnaire can also be used to study how to improve elderly people's behavioural intention to actual usage towards smart products in future research. Further discussion will be conducted in the following paragraphs. Compared with existing ageing-oriented design approaches (e.g. 37,55], which mainly emphasise usability, accessibility, or general healthcare functions, the proposed framework advances the field by directly integrating TAM variables (PU, PEOU, SE, PE) with design variables (ID, FD, AD). This integration provides a structured link between behavioural acceptance and concrete design elements, offering a more holistic and practical framework tailored specifically to diabetic elderly users. In this way, the proposed framework addresses both psychological acceptance and product usability, which are often considered separately in previous frameworks.

Internal variables that are positively associated with elderly behavioural intention

Table 11 shows the hypothesised path results. For the hypothesised BI to AU path, the standardised path factor was 0.328, which reached an obvious level ($p < 0.05$), which means that path H11 determined elderly people's final acceptance towards smart products, therefore, the variables that can influence BI should receive more attention. The hypothesised path from PEOU to PU had a standardised path factor of 0.257 and showed that path H6 was significant ($p < 0.05$). The hypothesised path from PEOU to BI showed that path H10 had a positive influence, and the results showed that the standardised path factor was 0.223 and reached a high level ($p < 0.05$). The hypothesised path PU to BI presented a standardised path factor of 0.244, indicating an obvious level and proving a positive path of H10. The hypothesised path from PE to BI had a standardised path factor of 0.202 and showed that path H2 was significant ($p < 0.05$). Hypotheses H1b and H2 proved that SE and PE also play an important role in determining BI since the results indicated that SE has a direct influence on BI. These findings indicated that internal variables such as PU, PEOU, SE, PE and BI are the critical internal variables that need to be considered.

Table 11. The hypothesised paths.

Paths	Standardised path factor	Non-standard path coefficients	S.E.	C.R.	<i>P</i>
FD→PEOU	0.264	0.312	0.084	3.719	***
AD→PEOU	0.176	0.228	0.086	2.651	0.008
ID→PEOU	0.225	0.318	0.103	3.091	0.002
FD→SE	0.273	0.222	0.059	3.784	***
AD→SE	0.113	0.101	0.059	1.726	0.084
ID→SE	0.163	0.159	0.07	2.28	0.023
FD→PU	0.159	0.176	0.08	2.208	0.027
AD→PU	0.167	0.202	0.079	2.57	0.01
ID→PU	0.194	0.257	0.095	2.698	0.007
PEOU→PU	0.257	0.24	0.071	3.409	***
SE→PU	0.142	0.193	0.093	2.073	0.038
FD→PE	0.221	0.19	0.06	3.148	0.002
AD→PE	0.153	0.145	0.061	2.379	0.017
ID→PE	0.094	0.097	0.073	1.33	0.183
PEOU→PE	0.195	0.142	0.055	2.557	0.011
PU→PE	0.163	0.127	0.062	2.03	0.042
PU→BI	0.223	0.235	0.084	2.801	0.005
PEOU→BI	0.244	0.24	0.076	3.175	0.001
PE→BI	0.202	0.274	0.099	2.777	0.005
SE→BI	0.192	0.274	0.094	2.911	0.004
BI→AU	0.328	0.393	0.081	4.838	***

External variables and elderly people's perceptions of smart products

In this study, the results also indicated that elderly users have positive perceptions of external variables (ID, FD and AD) about smart products and strong behavioural intention to adopt them. The findings align with the researchers' expectations as elderly participants are open and willing to learn and accept new smart products. Theoretically, our hypothesised model indicates that key smart product design variables including ID, FD and AD support elderly people in better understanding smart product technology, which in turn promotes their acceptance of smart products, and hence their intention to use them. Specifically, elderly users perceived that FD and ID were very helpful in improving their ease of using smart products. They believed that PEOU, PU and PE are greatly met through the improved design of smart products. They also felt that they could develop an understanding of healthy diet knowledge and form a habit of using smart products. The questionnaire results indicated that these elderly users are well-positioned to experiment with emerging smart products that are well-designed. The hypothesised path FD to SE tested a standardised path factor of 0.273 and showed path H5c significant level and influence ($p < 0.05$). The hypothesised path from FD to PE tested a standardised path factor of 0.221 and showed that path H5d was significantly influential ($p < 0.05$). The hypothesised path ID to PEOU had a standardised path factor of 0.225 and had a significant influence on path H3b ($p < 0.05$), followed by SE and PU.

Relationships among TAM variables

By investigating the key variables that can influence elderly people's acceptance, a proposed framework for smart product design for diabetic elderly can be developed based on the identified hypothesised paths.

The results are shown in Table 7. The most influential variables on elderly users' behavioural intention to use smart products are PEOU and PU. The external variables are FD, AD and ID. According to the results, FD influenced PEOU most which tested a standardised path factor of 0.264 and showed path H5b significant level and influence ($p < 0.05$). Therefore, an effective FD of smart products can significantly improve the elderly' acceptance towards smart products. ID influence SE and PU with high-level standardised path factors of 0.163 and 0.914, presented H3c and H3a. When elderly users have high PEOU, they believe that smart products can help them manage their daily tasks easier and better, such as improving efficiency and quality of life. This shows that if the government or organisations want to promote the integration of smart products among the elderly, they need to help them understand the function of these products, as well as improve the interface of operation. When elderly users understand the function of smart products, it is likely to improve their behavioural intention to use them. Finally, Figure 4 elaborates the relations clearly with a proposed framework for smart product design for diabetic elderly based on TAM.

Implications of framework in rehabilitation

This section outlines how the validated ageing-oriented smart product design framework can be applied in real-world rehabilitation contexts for ageing populations. The validation confirmed its practicality and effectiveness in addressing technology acceptance among elderly users with diabetes. The framework was implemented through a structured process.

Step 1, illustrated in Figure 7, begins with a planning phase establishing the foundation for the design process. It identifies the main challenges faced by elderly individuals with type II diabetes in maintaining a healthy diet, such as tracking nutrition, understanding medical advice, and using digital health tools. The target users are defined based on demographics, health conditions, digital literacy, and lifestyle. A market analysis is conducted to assess existing smart health products, identifying gaps in features, usability, and accessibility. These findings are evaluated to balance user needs and technical feasibility. The conceptual design phase then translates insights into design objectives and user profiles aligned with promoting healthy diet compliance and independent living. User personas represent the needs and motivations of the target group, guiding human-centered design decisions. Competitive analysis refines product positioning, and evaluation criteria are established for later stages. Functional definition, need analysis, and targeted interviews deepen user understanding, while literature insights provide theoretical support. The outcome of Step 1 is a set of defined user needs and design variables forming the blueprint for subsequent development.

Step 2, shown in Figure 8, transitions from conceptual understanding to the formal specification of design requirements through the questionnaire and interview. User needs and design variables from Step 1 are translated into appearance, interface, and functional requirements. Based on questionnaire results, the interface design focuses on easy interaction, minimal input, and clear navigation suited to limited dexterity and cognitive ability, the appearance design focuses on visual accessibility, incorporating high-contrast colour schemes, large and legible typography, and a clean, uncluttered layout that reduces cognitive load, and the function design was transferred from questionnaire and further interview in future research.

Step 3, shown in Figure 9, aligns the design variables with TAM to enhance user acceptance. Design strategies target four TAM variables—PU, SE, PEOU, and Perceived PE—through improvements in AD, ID,

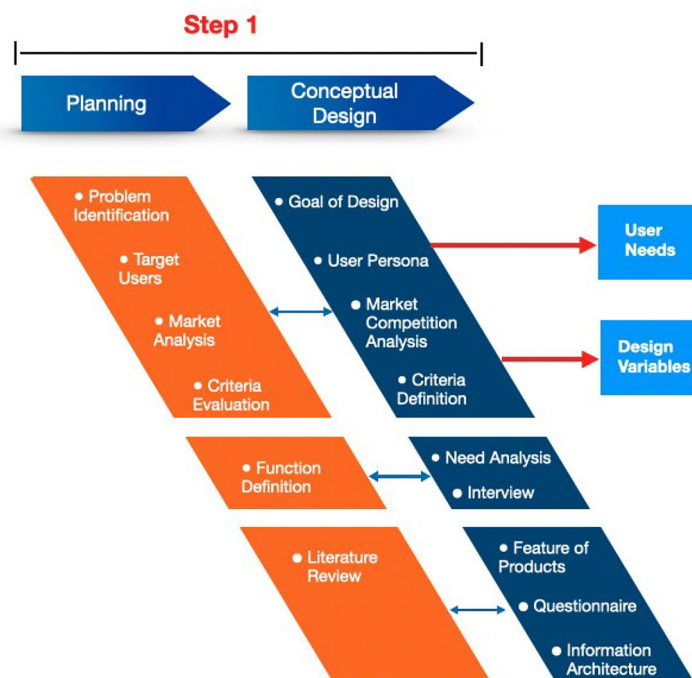


Figure 7. Step 1 of framework: planning and conceptual design process. This diagram illustrated the guidance and steps of how to apply the proposed framework, the first step is the beginning of conceptual design and data collection in the initial design process.

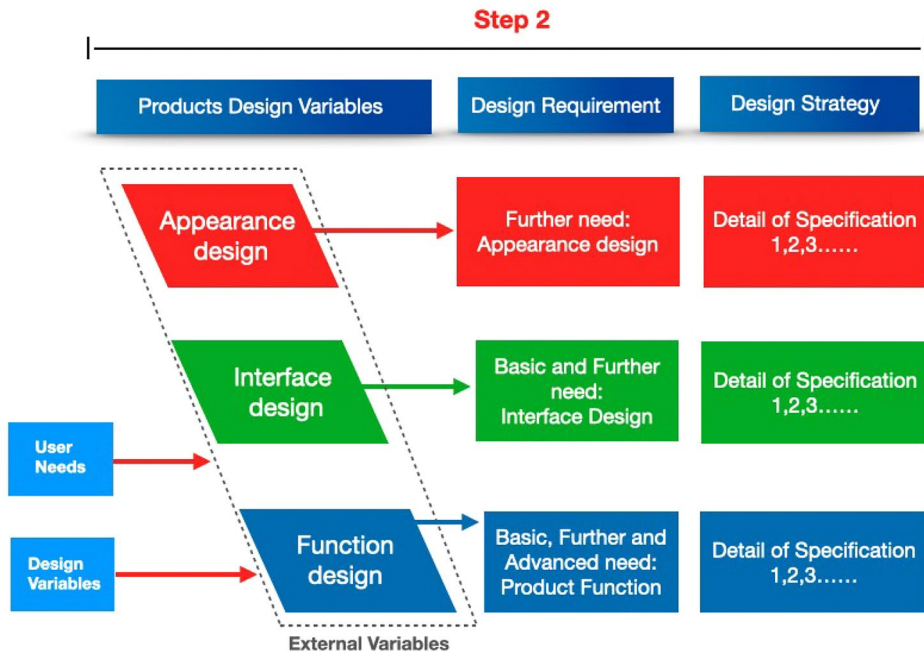


Figure 8. Step 2 of framework: identify design variables and user needs. This diagram illustrated the guidance and steps of how to apply the proposed framework, the second step is the methods to transfer user needs and design needs to products design and design strategy.

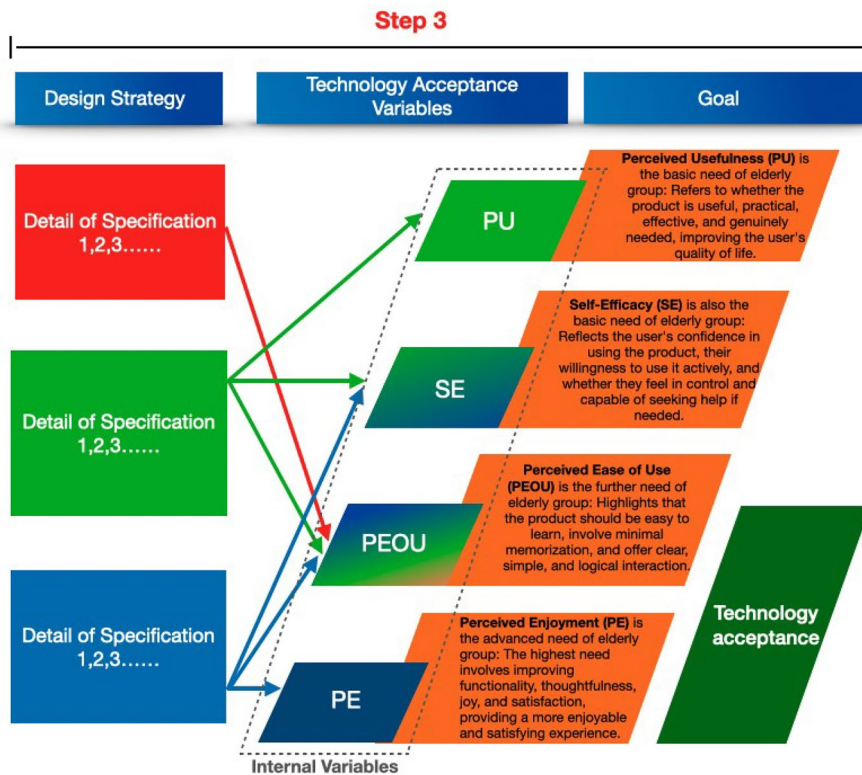


Figure 9. Step 3 of framework: design strategy integrated TAM variables for technology acceptance. This diagram illustrated the guidance and steps of how to apply the proposed framework, the third step is the relationship between TAM variables and design variables, which provide a clear guidance to improve the elderly's acceptance through accurate product design variables.

and FD, based on questionnaire findings. PU is strengthened by product interface design. SE is promoted through the product function design and interface. PEOU is enhanced by all the three design variables including appearance, interface and function design. PE is increased with product function design.

For example, the empirical relationships among the TAM variables can be translated into concrete design strategies that guide the development of ageing-oriented smart products. Enhancing PEOU requires intuitive interaction mechanisms—such as simplified menu structures, high-contrast visual layouts, and error-tolerant input systems—to reduce cognitive and physical effort. Increasing PU involves embedding features that directly support diabetic self-management, including personalised reminders, real-time health tracking, and accessible data summaries that demonstrate tangible benefits to users. Strengthening SE can be achieved through progressive learning functions, voice-assisted guidance, and supportive feedback that foster confidence in device operation. Promoting PE entails incorporating engaging aesthetics, positive feedback tones, and adaptive personalisation to enhance emotional satisfaction [56]. Collectively, these empirically supported design principles operationalise TAM constructs into actionable guidelines, ensuring that the framework not only predicts acceptance but also directs the creation of inclusive, rehabilitation-oriented smart products for elderly users. Figure 10 is the final framework after expert review. By addressing these differences, the framework ensures inclusivity and enhances the likelihood of wider acceptance across heterogeneous elderly populations.

The framework also offers significant value to stakeholders. For product designers, it provides a structured methodology for creating ageing-oriented smart products. Healthcare providers can serve as tools to support diabetic management among elderly patients, potentially reducing healthcare costs and improving quality of life. Policymakers offer insights for developing standards and guidelines for smart elderly care products, fostering innovation in this growing market. To ensure effective implementation, the framework can be integrated into product development processes, emphasising user-centered design and TAM variables. Collaboration with healthcare providers ensures alignment with clinical guidelines, whereas pilot testing and iterative refinement address real-world user needs. Training and support for end-users, scalability for cross-cultural adaptation, and advocacy for policy and industry standards further enhance its applicability.

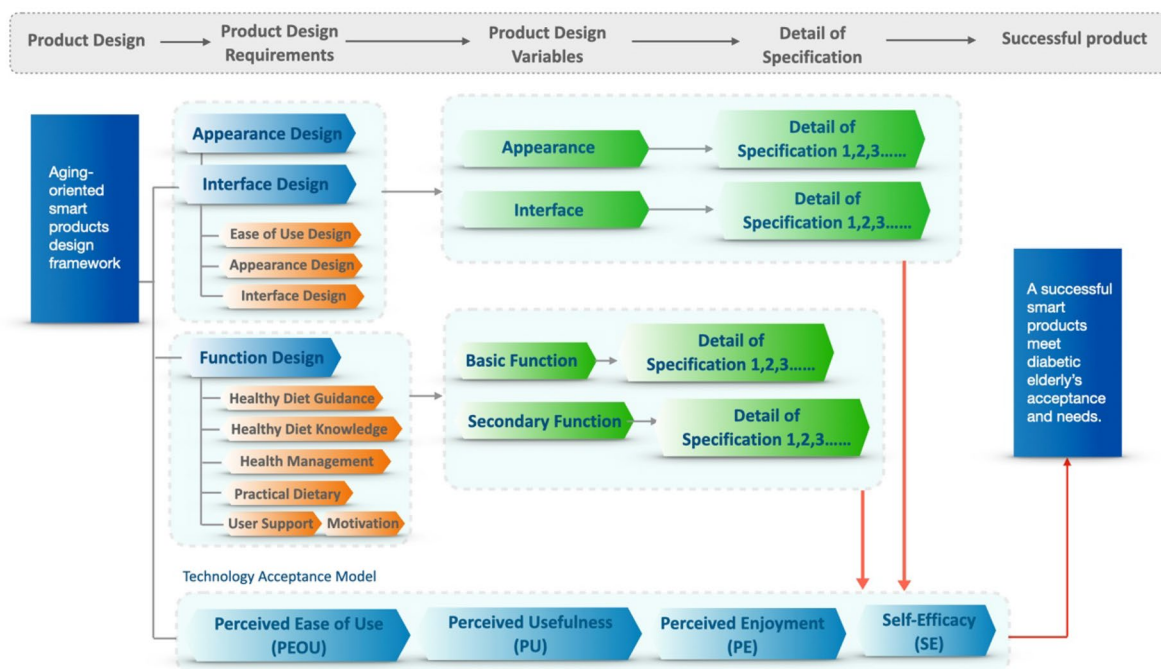


Figure 10. Validated ageing-oriented interface design of smart products framework. The verified framework through expert review. Validated ageing-oriented smart product design framework showing appearance, interface, and function design feeding into product variables and detailed specifications. Technology Acceptance Model factors—Perceived Ease of Use, Usefulness, Enjoyment, and Self-Efficacy—support development of a successful product that meets diabetic elderly users' needs.

In summary, the framework offers a systematic, user-centered approach to ageing-oriented interface design. By addressing appearance, interface, functionality, and technology acceptance, it ensures that smart products are both practical and user-friendly, supporting the rehabilitation and health needs of diabetic elderly individuals. Although the study focused on elderly participants with prior smart product experience, subgroup SEM analyses confirmed consistent structural relationships across different digital literacy levels (see supporting document). Despite its contributions, this study has several limitations. Due to practical constraints, convenience sampling was employed, as random selection was not feasible. Although online procedures were used to reach a diverse group of participants, the lack of randomisation may limit the representativeness of the findings. Moreover, the exclusion of complete non-users remains a limitation; future research should include elderly individuals with no prior technology experience, using stratified random sampling and scenario-based items to enhance generalisability. The validation of the proposed framework was restricted to expert review owing to methodological and time constraints, and its applicability in real-world contexts has yet to be empirically tested. Cultural and contextual factors may also influence the results, as participants and experts were primarily drawn from a specific geographic and social background, potentially affecting elderly users' perceptions and acceptance of technology across different regions. In addition, technological factors—such as device availability, internet connectivity, and digital literacy—may further constrain the framework's generalisability. Future research should therefore undertake longitudinal and cross-cultural studies to capture behavioural changes over time and to verify the model's universality. Real-world usability testing and pilot implementations in diverse healthcare and community rehabilitation settings are also recommended to refine the framework and ensure its practical relevance and adaptability in supporting diabetic elderly individuals' healthy diet management.

Conclusion

This paper proposes an ageing-oriented smart product design framework based on TAM. Through systematic methods including literature review, questionnaire and expert review, key variables that influence elderly people's acceptance are identified and used to propose and validate a design framework. The results indicated that BI is the key variable connecting to elderly people's acceptance, PE, PEOU, PU and SE are the important internal variables that influence BI. The external variables FD and ID are the most important external variables that influence BI indirectly during the smart product design process. The internal variables PEOU and PU most influence elderly users' intention to use smart products. FD strongly impacts PEOU, and ID influences both PEOU and PU, thereby enhancing acceptance. Therefore, high PEOU, FD and ID make elderly users believe that smart products improve efficiency and quality of life. This paper explored the structural relationships among TAM and design variables that predict the elderly population's behavioural intention to accept smart products in compliance with healthy diets. However, this study has limitations. Due to methodological constraints and the current stage of research progress, the proposed framework has only been validated through expert review and has not yet been tested in real-world settings. Future research will extend this work by conducting further investigations into the daily dietary needs of diabetic elderly and implementing usability testing in practical contexts to refine and validate the framework in real-world applications.

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Author contributions

CRedit: **Jinglong Li**: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Resources, Validation, Visualization, Writing – original draft, Writing – review & editing; **Rosalam Che Me**: Funding acquisition, Methodology, Project administration, Supervision, Writing – review & editing; **Faisul Arif Ahmad**: Funding acquisition, Methodology, Software, Supervision; **Qisen Zhu**: Conceptualization, Resources, Software.

Disclosure statement

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Data availability statement

Data is available upon request. Data related supporting documents are available at: <https://figshare.com/s/678a8889de2838ed5354>.

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