

Article

Sustainable Design for the Silver Society: Developing the Silver Model for Gerontechnology Product Innovation

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Abstract: In response to the challenges posed by an aging society, the field of gerontechnology has evolved, integrating technology with gerontology to enhance designs tailored for the elderly. Recent developments in the silver economy have underscored the substantial demand for these products, yet their development is frequently impeded by the absence of holistic design frameworks that encompass system design, technology, business strategy, and emotional considerations. To bridge this gap, our study employs a standardized Grounded Theory methodology to analyze product data and customer reviews from e-commerce platforms, supplemented by insights from interviews with four leading product designers in this sector. This analysis led to the creation of the ‘Silver Model’ for gerontechnology product design. This model integrates essential design aspects across eight domains, offering a comprehensive framework that harmonizes technological capabilities with the expectations of elderly users. This research advances the theoretical foundations of gerontechnology and furnishes a pragmatic blueprint for enhancing product design in the silver market, significantly contributing to the advancement of age-friendly technology and promoting both social and economic sustainability.

Keywords: design model; aging society; grounded theory; social sustainability



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1. Introduction

In 2022, a United Nations report highlighted the rapid global growth of the older population, noting that those aged 65 and over are increasing at a faster rate than the population under 65. As a result, the proportion of individuals aged 65 and over is projected to rise from 10 percent in 2022 to 16 percent by 2050. By that time, this demographic is expected to outnumber the population of newborns under the age of five [1]. Moreover, a 2015 joint report by the EU and Oxford Economics indicated that the “silver economy”, driven by population aging, contributes over EUR 4.2 trillion to global GDP and supports more than 78 million jobs. This contribution is expected to reach EUR 6.4 trillion and 88 million jobs by 2025 [2]. Given these trends, addressing the needs of aging populations is critical for the social and economic sustainability of societies worldwide.

The World Bank’s 2016 Golden Ageing Report argues that enhancing the quality of life of older individuals through supportive environments and products can significantly contribute to the sustainability of aging societies. The report underscores the importance of geriatric technology products, which integrate geriatrics and technology to improve the quality of life for older people. These products enhance living standards by providing health monitoring, assisted living solutions, medical support, and smart home technologies [3].

Despite their potential, many of these products lack a comprehensive and systematic design approach. They often rely more on designers' past experiences than on research-based, systematized model [4]. As a result, these products frequently fail to meet the multifaceted needs of older individuals, limiting their ability to fully engage with and benefit from these technologies. This gap underscores the need for robust design frameworks that reconcile user needs, values, business strategies, technological capabilities, design ethics, and cultural responsibility, viewing design trends as systemic issues [5]. To date, the Silver Design has been successfully implemented within a systemic design framework [6].

Our research has developed a "Silver Model" for the design of aging technology products, which aims to promote the sustainability of a silver society (aging society) and a silver economy (aging economy) by focusing on the silver segment of society through design. The model seeks to address existing gaps by providing a comprehensive and systematic design framework. It emphasizes key sustainability principles—environmental, social, and economic—through user-centered design practices that prioritize product longevity, user and social inclusion, and iterative optimization [7]. In doing so, it ensures that older individuals and their families can fully participate in society and benefit from aging technology. By integrating insights from technology, design, gerontology, and business strategy, the Silver Model provides a holistic framework that supports the development of products that are not only technically feasible but also socially and culturally appropriate.

2. Literature Review

2.1. Designers: Development of Gerontechnology Products

The application of gerontechnology has undergone years of exploration and trials. Researchers as early as 2001 integrated technology solutions in elderly care facilities, suggesting that new developments in assistive devices could make significant contributions to the care of individuals in elderly institutions and homes. Devices such as video surveillance, remote health monitoring, electronic sensors, fall detectors, door monitors, bed alarms, pressure mats, and smoke and heat detectors can enhance the safety, security, and home management capabilities of the elderly [8]. Even in an era when the concept of smart homes was not yet widespread, the University of Tokyo's research center conducted a systematic analysis of living spaces for the elderly using gerontechnology, exploring its application from multiple perspectives including behavior, technology, and cost [9].

With the advancement of technology in the 21st century, technology has become more compact in the form of mobile gerontechnology devices. Scholars have tried replacing traditional medical instruments with wearable gerontechnology devices in the medical and nursing processes for the elderly [10], and have developed wearable devices to monitor vital health data like heart rate [11], blood pressure [12], and oxygen saturation [13]. Applications in medical care, alongside the development of remote information technology, have also explored the design of remote medical gerontechnology devices [14]. As these technologies continue to evolve in specialized fields, they gradually integrate into the lives of the elderly. Smart homes for the elderly are gaining attention, ideally offering safety, health, mobility, personal hygiene, and care [15]. Gerontechnology has gradually merged medical devices into everyday items such as mobile phones [16] and watches [17]. With the recent developments in virtual reality and artificial intelligence, researchers and designers have not overlooked this important demographic; applications of virtual reality technology have been proven to effectively improve the psychological well-being of the elderly [18] and can be used for assessing the living spaces of the elderly [19]. In medical care, the combination of gerontechnology devices and artificial intelligence can provide precision medicine and disease prediction for the elderly [20]. However, despite the abundance of research, these technologies and products have not fully penetrated the lives of the elderly,

as there continues to be a gap between research and practice, and between design and production [21].

2.2. Users: Multifactorial Study on the Attitudes of the Elderly Towards Gerontechnology Products

Although the elderly generally have a positive attitude towards gerontechnology products, their willingness to purchase and use certain products varies, often shifting from initial reluctance to acceptance through specific opportunities [22]. Some researchers attribute this initial reluctance to psychological resistance to new technologies [23–25]. However, others apply the Technology Acceptance Model (TAM), a quantitative tool that elucidates the factors influencing new technology adoption. Further studies have shown that the elderly are not inherently opposed to gerontechnology products; in fact, they demonstrate significant interest and a positive disposition towards continued use. The negative emotions experienced by the elderly are influenced by personal, technological, and environmental factors, as well as by design elements that can be improved by designers [26–28]. Additional research by Salman emphasizes that the user interface significantly affects elderly users' acceptance of these products, considering factors such as input efficiency, information readability, and the integration of display and sound [29,30]. For example, tailored design of search interfaces and attention to elderly users' preferences have notably enhanced user satisfaction and efficiency [31]. Moreover, factors like the cost of use [32], psychological security [27], and perceived shame [33] also critically impact elderly acceptance of these products.

Despite considerable research identifying various design directions for gerontechnology products, inherent design limitations persist, primarily due to the fragmented nature of these studies. Most research tends to focus on isolated aspects, leading to a lack of comprehensive research that integrates and applies these designs across different scenarios.

2.3. Research on Relevant Design Models

Current research on product design models typically categorizes them into two groups: analysis-focused and practice-focused models. Analysis-focused models, such as the Double Diamond Design Model, KANO Model, and SWOT (S—Strengths, W—Weaknesses, O—Opportunities and T—Threats) Model, generally serve as universal frameworks that provide open-ended guidance on the design process and thinking from a macro perspective. However, they often fall short in addressing specific design challenges. More detailed studies, like the inclusive design process model proposed by Lucke and Castro [34], which draws on systems engineering and project management principles, aim to systematically integrate inclusive design into the development process, offering a framework for the reuse and interoperability of inclusive design systems. Nevertheless, the foundation of this research is the analysis and integration of various models, and it notably lacks practical examples.

The practice-focused category, exemplified by the inclusive design method developed by Waller et al. [35] at the University of Cambridge's Engineering Design Centre, strives to accommodate customer diversity throughout the development process to cater to a broader audience. This approach has prompted companies such as BT and Nestlé to adopt more inclusive design practices, illustrating the business case for inclusivity. Wilson [36] and colleagues, through practical inquiry, interviewed experts and designers in the sports field to explore human-centered inclusive design in sports, resulting in a series of actionable recommendations. Although this type of research originates from practical application, its broader applicability is limited because design is inherently complex and context-dependent, with no “silver bullet” solution for all complex design issues [37].

The examination of these design models underscores the diversity and breadth of existing approaches in both theory and practice, emphasizing the ongoing need for innovation and enhancement of design tools in this dynamic field. O’Grady [38] observed that the demands of the contemporary information age introduce unique challenges, necessitating the development of new, more specific design methods. Yet, existing models still often lack comprehensive and systematic approaches, highlighting the need for more structured and objective design methodologies.

3. Research Method

3.1. Selection and Comparison of Research Methods

Before initiating our study, we thoroughly evaluated various research methodologies, focusing on traditional methods such as one-on-one interviews, focus group discussions, user experience observations, and surveys.

Although these approaches are foundational in design research, aiming to synthesize models from diverse data and perspectives, they are frequently constrained by their theoretical nature and often suffer from insufficient knowledge exchange within teams [39].

In the development of age-friendly gerontechnology products, designers typically rely on their experience and intuition. As posited by the SECI (Socialization, Externalization, Combination, and Internalization) theory [40], effective team-based product development necessitates a balance between tacit and explicit knowledge. Explicit knowledge, such as models, formulas, and texts, can be easily communicated, whereas tacit knowledge, encompassing experience and intuition, is challenging to articulate and share, leading to design processes that lack model support and rely predominantly on tacit knowledge. This can result in significant challenges in communication and iteration.

Recognizing these challenges, our study aimed to externalize tacit knowledge and develop discussable, replicable design models. However, traditional tools such as questionnaires or structured interview templates can introduce biases and errors. These tools are often subjectively designed by researchers and may encounter issues like inadequate population representation, data misinterpretation, compromised answer integrity, and unsatisfactory response rates [41,42].

To systematically and objectively address these design challenges, we employed Grounded Theory [43], an ideal methodology for developing strategic models in gerontechnology product design. Grounded Theory enables the progressive coding of extensive case studies, data, and interview materials to derive abstract concepts and establish new design models and guidelines. Specifically, this methodology was utilized to analyze product data and customer reviews, offering a structured approach to integrate insights systematically. Interviews with product designers were meticulously integrated into this analysis by coding their responses and aligning them with emerging themes, thus enhancing the methodological rigor and credibility of our study. This approach ensures that design models are not only grounded in empirical data but also reflect comprehensive customer needs and expert insights.

3.2. Research Planning

This study aims to develop a “Silver Model” for designing technological products for the elderly, in the context of the trends of social silverization (aging society) and economic silverization (aging economy). This model aims to generate reliable outcomes through qualitative research utilizing Grounded Theory, incorporating case materials and expert interviews for analysis. Despite the current lack of a systematic gerontechnology product design model in existing research, there is an abundance of gerontechnology case studies available for examination. Consequently, this study employs purposive sampling to gather

specific product reviews, descriptions, and promotional materials from Amazon and eBay. Research indicates that analyzing product reviews on e-commerce platforms provides spontaneous and impartial insights, free from any conflicts of interest. These reviews offer valuable experiential knowledge and precise validations, which are instrumental in devising effective strategies for the design of technology products for the elderly [44]. The primary objective of analyzing product content on eBay's trading platform is to reflect the influence of symbolic interactionism in product reviews and to investigate the perspectives and meanings conveyed by the participants. This approach underscores the actions undertaken by individuals within society and the consequent perceived effects of these actions. Given that many products on eBay are sold only once or twice by individual users, the expressions tend to be highly specific and targeted, offering unique and personalized insights. Thus, case materials and interviews with design experts will serve as the primary data sources for this study.

To develop a design model for gerontechnology products aimed at the elderly, we chose to implement standardized Grounded Theory coding steps [43]. This method allows researchers to minimize biases during the research execution and to complete the modeling in the absence of existing models and prior theoretical knowledge. The standardized Grounded Theory coding process is divided into four stages: data collection, data analysis, checking for theoretical saturation, and theoretical coding (see Figure 1).

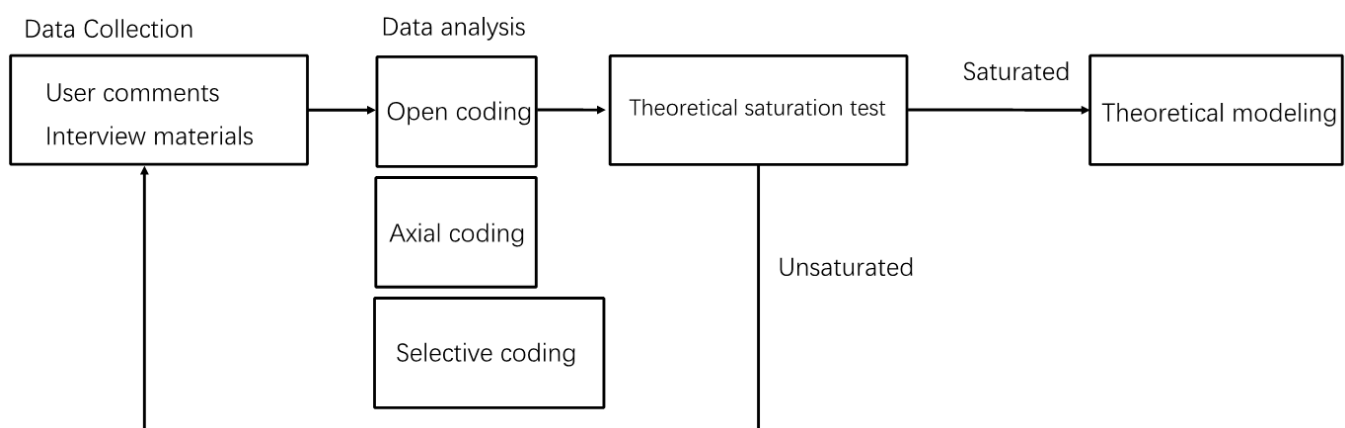


Figure 1. The standardized Grounded Theory coding steps.

During the coding process, the team examined various gerontechnology product designs and inclusive design studies using three-level coding. To maintain objectivity in data interpretation and minimize bias, the Consensual Qualitative Research (CQR) method [45] was implemented. In this three-level coding system, each phase was overseen by two PhD students who were tasked with coding and discussing the data. Additionally, a graduate student in design studies reviewed the results. Once validated, the coding outcomes from each phase were carried forward to the next, ensuring consistent use of research data by the researchers throughout each stage.

3.3. Data Collection

To capture diverse perspectives from users, their family members, and designers during the modeling process, this study employed three primary data sources: 1. Product case data from e-commerce platforms, 2. Product promotional content from the eBay trading platform, and 3. Semi-structured in-depth interviews with professional designers and experts.

3.3.1. Product Data and Reviews

To refine our product selection methodology, the research team identified target products at the intersection of gerontology, aging science, and technology. These products are intricately designed to either prevent, delay, or compensate for sensory, cognitive, and physical declines associated with aging, or to enhance opportunities for communication, leisure, learning, service, and artistic expression among older adults. This strategic choice was guided by classifications from previous research, which delineate elderly technology products into four principal categories: home and daily life technology, communication technology, health technology, and education and entertainment technology [46].

In our systematic review of the Amazon e-commerce platform, we utilized these categories to direct our product search and selection process. Using Consensual Qualitative Research (CQR) [45] based on the search results, we identified innovative design features across a diverse array of products, segmented into handheld devices, wearable devices, and fixed household devices. Intensity sampling was employed to select products, prioritizing those with extensive reviews which indicated substantial user engagement and potential impact. Post-CQR, triangulation was conducted by two researchers and a reviewer to refine our product list, removing duplicates and products with inadequate feedback. This process confirmed that our selection encompassed the four major categories and three key design features of elderly technology products. Initially, twenty products remained; however, after conducting a saturation comparison test between these product lists and a related review article [47], it became apparent that certain representative products were missing from the identified categories and design features. This led to the inclusion of further items, such as electronic pill dispensers and devices for continuous data monitoring, culminating in a finalized list of twenty-eight representative products. Further saturation testing with two related research reviews [48,49] confirmed that these products comprehensively represent the types of mass-produced elderly technology products in the market.

In terms of data collection from Amazon, in addition to product data, extensive review data were also required. Due to the inefficiencies of manual selection, this study leveraged web scraping technologies to extract reviews via the legally compliant “iSellerPal” (<https://www.isellerpal.com/>), which circumvents Amazon’s restrictions on unauthorized data capture. Aimed at Amazon vendors and manufacturers, this software provides authorized access to product summaries and reviews. To assess the influence of symbolic interactionism on product reviews and to extract meaningful perspectives from participants, an intensity sampling method was adopted post-review collection. This method selected reviews that were either positive or critical, but all were required to be constructive and purposeful rather than mere expressions of vague approval or disapproval. Ultimately, data from 59 products across multiple regions were compiled, including 28 from Amazon (for further details, please consult Appendix A) that featured substantial reviews alongside developmental documents and promotional materials. eBay’s contribution to the dataset included product information from sales pages. Therefore, the collection of comprehensive data from these e-commerce platforms was completed, and the data composition includes insights from multiple identities such as the elderly, social institutions, family members, and caregivers.

3.3.2. Designer Interview

We conducted semi-structured, in-depth interviews to gather data on the diverse meanings and perceptions of behaviors and events. Our participants included four professional designers and six design graduate students across various related fields, with a gender distribution of six males and four females. Those interviewees consenting to disclose their identities included a designer from the Daimler Mobility Services brand StarRides and a

product designer responsible for Banggood Technology Co., Ltd.'s operations on Amazon Marketplace. Additionally, graduate and doctoral students from the University of Malaya, Guangzhou University, and Guangzhou Academy of Fine Arts participated. Respondents who opted not to remain anonymous will be acknowledged in the acknowledgments section of our publication.

The interview framework's first part focused on the respondents' experiences and views related to gerontechnology product design and age-friendliness. The second part involved the respondents commenting and redesigning existing cases of gerontechnology products [50].

3.4. Data Analysis

We conducted data analysis using NVIVO 14, which involved three parts: open coding, axial coding, and selective coding.

The coding process followed a three-level coding procedure. After the initial data collection was completed, researchers were required to code product reviews and interview data without any preconceptions or biases.

3.4.1. Open Coding

Based on raw data, concepts were extracted using the "Code in vivo" method. The advantages of this method include ensuring objectivity and speed, though it often results in generating codes with different concepts but identical meanings, thereby increasing the workload for the axial coding phase.

The open coding results were discussed openly, using a Boolean union method. After discussions and reviews, a total of 548 initial nodes were generated, including concepts like alarm systems, activity monitoring, battery life, battery endurance, corporate social responsibility, dementia, clarity, plain packaging, and simple installation.

3.4.2. Axial Coding and Selective Coding

Two researchers engaged in axial coding of the open coding results, utilizing both deduction and induction to integrate related codes through constant comparative analysis. Unlike materials associated with behaviors or processes, this study focused on product descriptions and reviews. Thus, semantic and design relationships guided the axial coding process. This study identified user identity information for specific groups, including the deaf, Parkinson's patients, and arthritis sufferers, categorized as 'Primary Users'. A significant disparity was observed in the frequency distribution of product reviews across different datasets. For instance, a voice-activated watch coded as A17 received 999 reviews, whereas a more expensive visual reader coded as A14 only garnered 84 reviews. This stark contrast indicates that frequency-based coding does not adequately capture the unique characteristics of different user experiences.

To address this, specialized category coding was implemented. Categories representing less than 25% of the data sources were combined into higher-frequency categories. As a result, 45 axial codes were established through collaborative discussions among researchers.

The analysis ultimately led to the identification of eight core categories, as shown in Table 1. Consensus was reached on seven of these categories, while 'Multi-generational user integration' was the subject of discussion, and was resolved through detailed conversations with reviewers. This refinement allowed the research to concentrate on the most significant themes, enhancing the depth and quality of the findings.

Table 1. Coding results.

Selective Coding	Axial Coding	Sub-Total for Opening Codes
Multi-generational user integration	Initial Purchasers (15), Primary Users (31), Secondary Users (22), Maintainers (8), Upgraders (8), Carrier Recycler (7)	91
Functionality customization for aging needs	Health and Safety Monitors (23), Accessible Information Hub (19), Adaptive Entertainment System (18), Simplified Communicator (15), Assistive Daily Living Aids (15)	90
Longevity-focused product design	Energy Efficiency and Longevity (12), Enhanced Durability (11), Reduced Environmental Impact (10), Modular Design (9), Comprehensive Life Cycle Analysis (8)	50
Age-sensitive emotional engagement	Family Emotions (17), Enhanced Social Support (15), Reassuring Safety Features (9), Self-Esteem Preservation (10), Companionate Interaction Emotions (14)	65
Gerontechnology-friendly technology adaptation	Widespread Technology Availability (12), Intuitive Technology Usability (11), Direct Pain Point Solutions (16), Simplified Technology Learnability (8), Universal Technological Accessibility (11)	58
Senior-centric interaction design	Enhanced Auditory Feedback (14), Voice-Activated Input (18), Optimized Visual Readability and Contrast (8), Simplified Tactile Interaction (7), Responsive Tactile Feedback (6), Motion and Stability Monitoring (6), Vital Sign Monitoring (8)	67
Integrated gerontechnology ecosystem	Comprehensive User Support (19), Responsive After-sales Service (15), Seamless Collaborative Integration (7), Marketing and Promotion (8), Outer Packaging (6), User Community (6)	61
Age-appropriate aesthetic design	Elderly-Friendly Styling (18), Muted Color Palette (10), Soft Texture Choices (7), Durable and Safe Materials (6), Ergonomic Comfort (13), Friendly Dimensions (12)	66

3.5. Theoretical Saturation Test

Theoretical saturation is a fundamental concept in Grounded Theory, representing the point at which additional data collection no longer produces new themes, concepts, or categories, thereby confirming that the research domain has been sufficiently explored. Theoretical saturation testing can be approached through two main strategies: progressive saturation testing and independent saturation validation.

At the early stage of this study, we employed the progressive saturation approach, where data were analyzed in increments of 100 entries at a time. However, through discussions within the Consensual Qualitative Research (CQR) framework [45], it became evident that the saturation process exhibited a wave-like pattern. While it initially appeared that the number of new codes was decreasing with each new data batch, the inclusion of data from certain products caused a sudden surge in the emergence of new codes. This fluctuation occurred for two key reasons. First, the data originated from different data sources (e.g., product data, user reviews, and interview data) with inherent differences in

their conceptual richness. Second, the data volume varied significantly across products, leading to irregular surges in the identification of new codes. As a result, the progressive approach was deemed unreliable for ensuring saturation.

In response to this issue, we adopted a more rigorous method, namely, independent saturation validation. Unlike the progressive approach, this method involves conducting a complete round of coding on the entire initial dataset before performing an independent saturation test. While this approach requires considerably more effort, it offers greater stability and reliability in the final coding results. The two saturation verification processes conducted during the data collection phase have ensured the saturation of product categories. This method enhances the stability and credibility of the coding process, ensuring that the final coding results are both conceptually exhaustive and theoretically robust.

For independent saturation testing, we selected five redundant products (with 84 different comments), which were excluded from early data collection CQR discussions. During the initial validation phase, two new initial nodes emerged, reflecting the natural exploratory process of concept development. However, these new nodes neither generated new axial codes nor influenced existing axial codes. As all additional data underwent a new round of coding, no changes were observed in the original results, indicating the achievement of theoretical saturation. The absence of new categories, despite introducing substantial new data, confirmed that the existing categories were comprehensive and conceptually exhaustive.

To further ensure robustness, we adhered to the CQR triangulation method outlined in the research design during the saturation test. This process involved two independent researchers and a reviewer who coded the data independently and reviewed results at each stage. Through a consensus-building process, the team discussed and validated coding outcomes, ensuring balanced and rigorous data interpretation. This method minimized potential researcher bias and enhanced the credibility of the findings.

The final results confirmed that the “eight aspects” represent a comprehensive and stable classification of considerations for gerontechnology product design. The introduction of five new products did not yield any new categories, affirming that the “eight aspects” sufficiently encompass the critical dimensions of gerontechnology design.

4. Research Results

4.1. Explanation of Coding

Following the Grounded Theory coding process, this study summarized eight core factors through selective coding. These eight core factors represent a comprehensive system consideration for the silverization of gerontechnology products.

4.1.1. Functionality Customization for Aging Need

The concept of “Functionality Customization for Aging Needs” (see Figure 2 for details) in gerontechnology focuses on tailoring product designs to specifically meet the nuanced requirements of elderly users, integrating various aspects of their daily lives to enhance usability and accessibility. This approach spans from health and safety features, ensuring devices like medication managers and emergency alert systems are simple and reliable, to information interactors that deliver time and text data in formats easily consumable by those with sensory limitations. Entertainment options are adapted to account for impaired vision or hearing, ensuring older adults remain engaged and connected. Communication tools are streamlined to facilitate easier interactions, supporting social connectivity despite physical or sensory challenges. Additionally, life assistant technologies aid in daily tasks and mobility, adjusting to the user’s physical capabilities and evolving needs. Together, these adaptations ensure that gerontechnology products not only address

the specific health, cognitive, and emotional requirements of the aging population but also promote a more independent, safe, and enjoyable quality of life, resonating deeply with the unique lifestyle of each user.

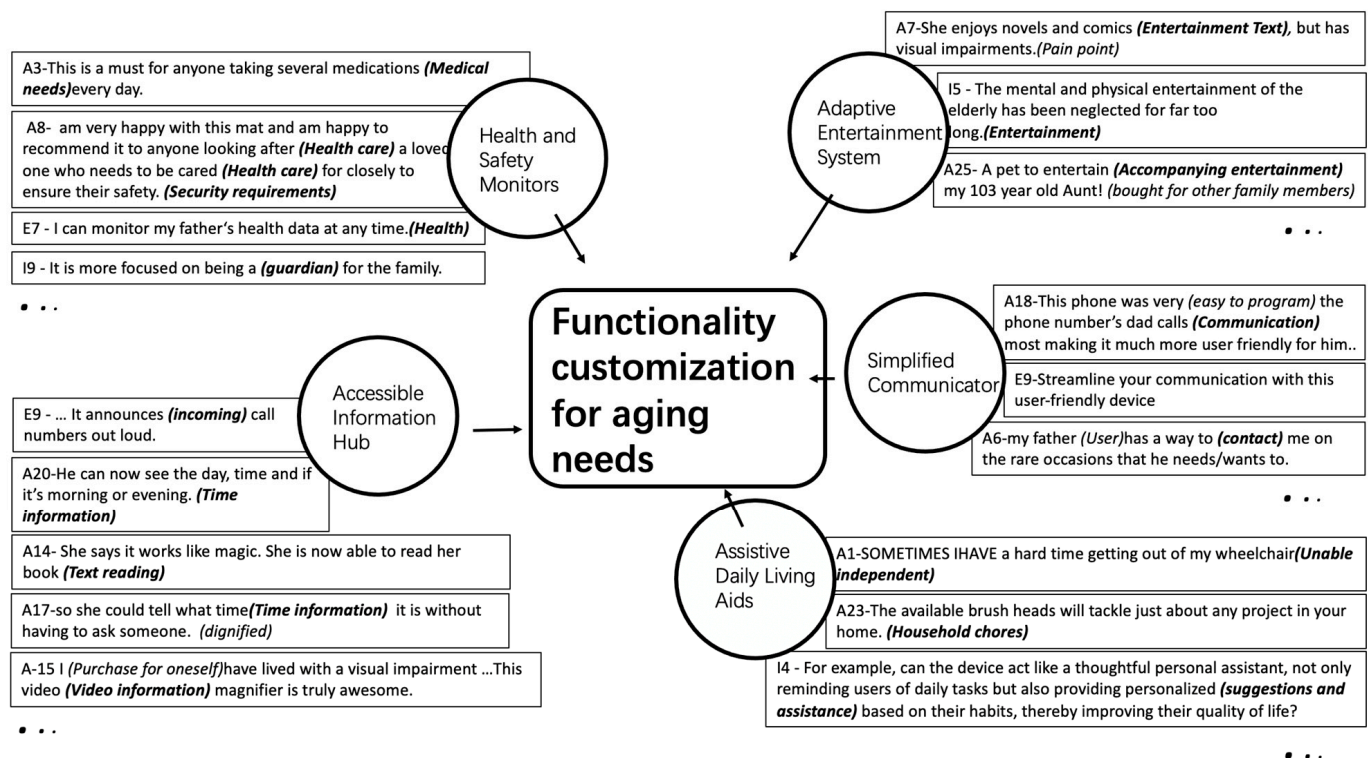


Figure 2. “Functionality customization for aging needs” data flow map.

4.1.2. Multi-Generational User Integration

Understanding “Multi-generational User Integration” (see Figure 3 for details) is crucial for designing gerontechnology products, as the distinct roles of family members, caregivers, and the elderly create a complex interaction landscape. For instance, purchasers—such as family members or agency representatives—select products like the cordless pressure pad with notification functionality (A8) for elderly dependents with cognitive impairments or mental health conditions. While primary users focus on functionality, they often rely on others for upkeep and technological support.

This distinction necessitates a user-centered design approach that clearly defines the roles of purchaser, user, and maintainer, addressing their unique needs and interactions with the product. Recognizing these roles is vital for ensuring the technology’s effectiveness in real-world settings, which is often overlooked in traditional models. Furthermore, interactions between primary and secondary users, such as family members and caregivers, must be considered to enhance usability and satisfaction [51].

Developing gerontechnology requires targeted research and design that accounts for these layered interactions, meeting immediate functional needs while supporting the entire product lifecycle—from decision-making and purchase to maintenance and eventual disposal.

4.1.3. Longevity-Focused Product Design

“Longevity-focused Product Design” (see Figure 4 for details) in gerontechnology prioritizes durability and modularity to address the specific needs of elderly users while aligning with sustainable practices that minimize environmental impact and economic burdens. Features such as replaceable batteries and adaptable components extend product

life and reduce the frequency of replacements, which is especially important for users on fixed incomes.

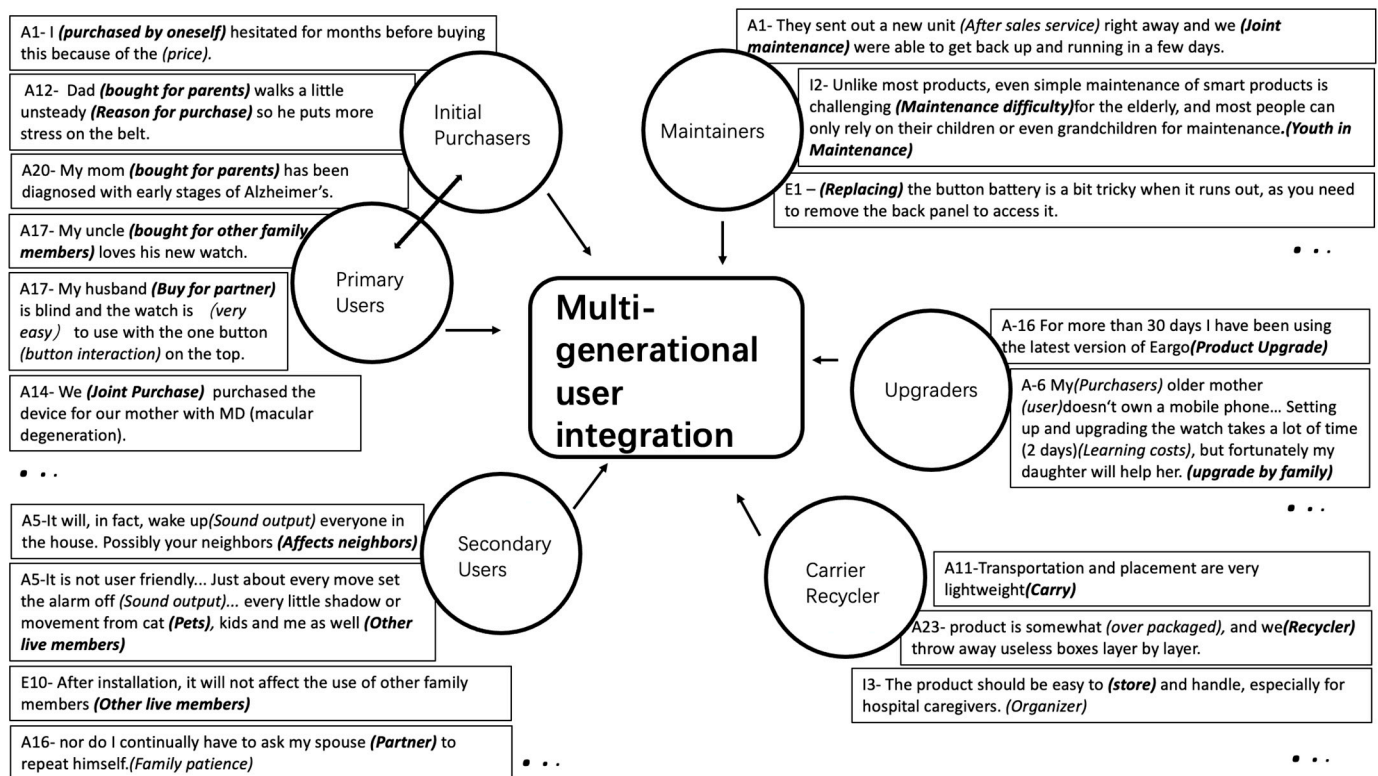


Figure 3. "Multi-generational user integration" data flow map.

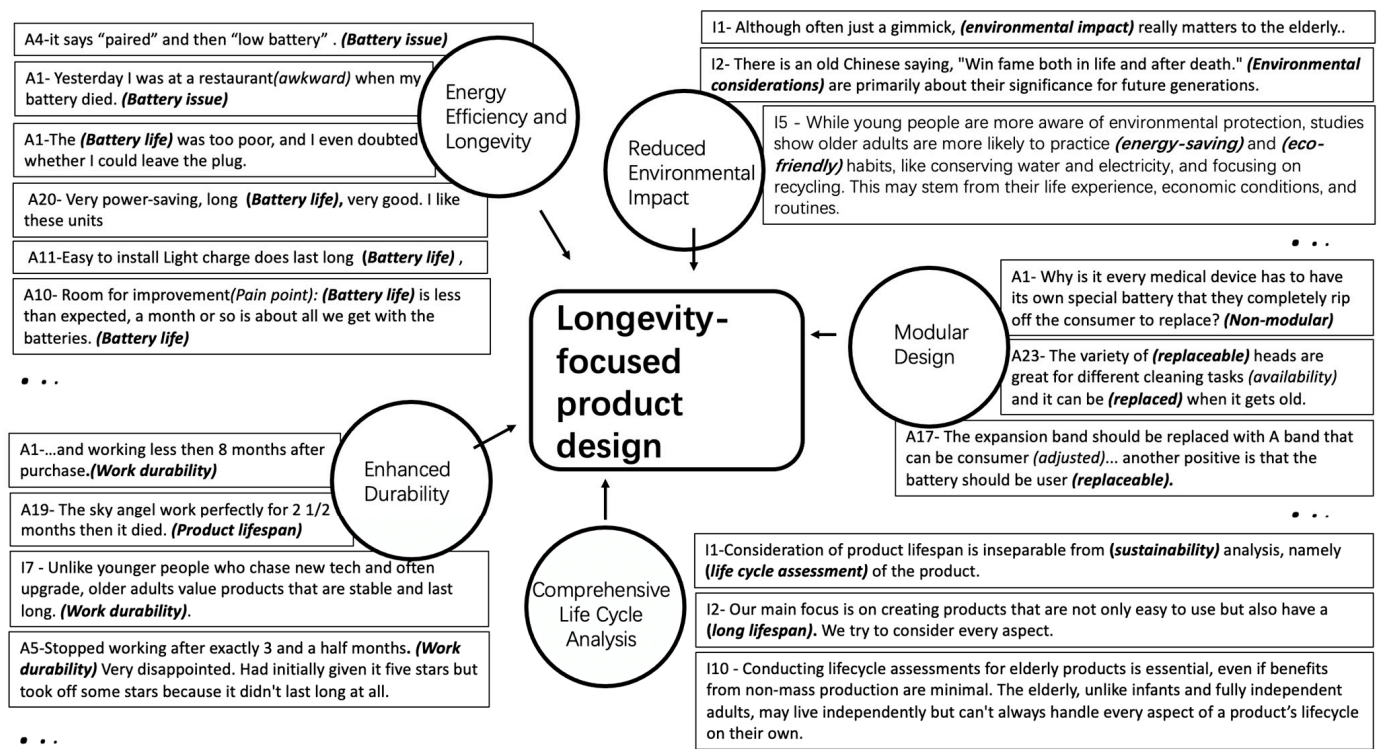


Figure 4. "Longevity-focused product design" data flow map.

By emphasizing energy efficiency and selecting robust, hypoallergenic materials, these products cater to immediate user needs and ensure long-term usability and environmental sustainability. This strategy aligns with the principles noted by Blažun et al. [52] and is supported by Alhyari and Gupta [53], who advocate for upgradeable designs to reduce resource waste and enhance user convenience.

4.1.4. Age-Sensitive Emotional Engagement

In gerontechnology, “Age-sensitive Emotional Engagement” (see Figure 5 for details) addresses the emotional and social needs of elderly users to enhance well-being and maintain social ties [54]. Design strategies should reduce emotional discomfort and promote positive interactions. For example, hearing aids feature user-friendly interfaces and skin-toned colors to minimize stigmatization, while discreet monitoring systems provide alerts without causing distress.

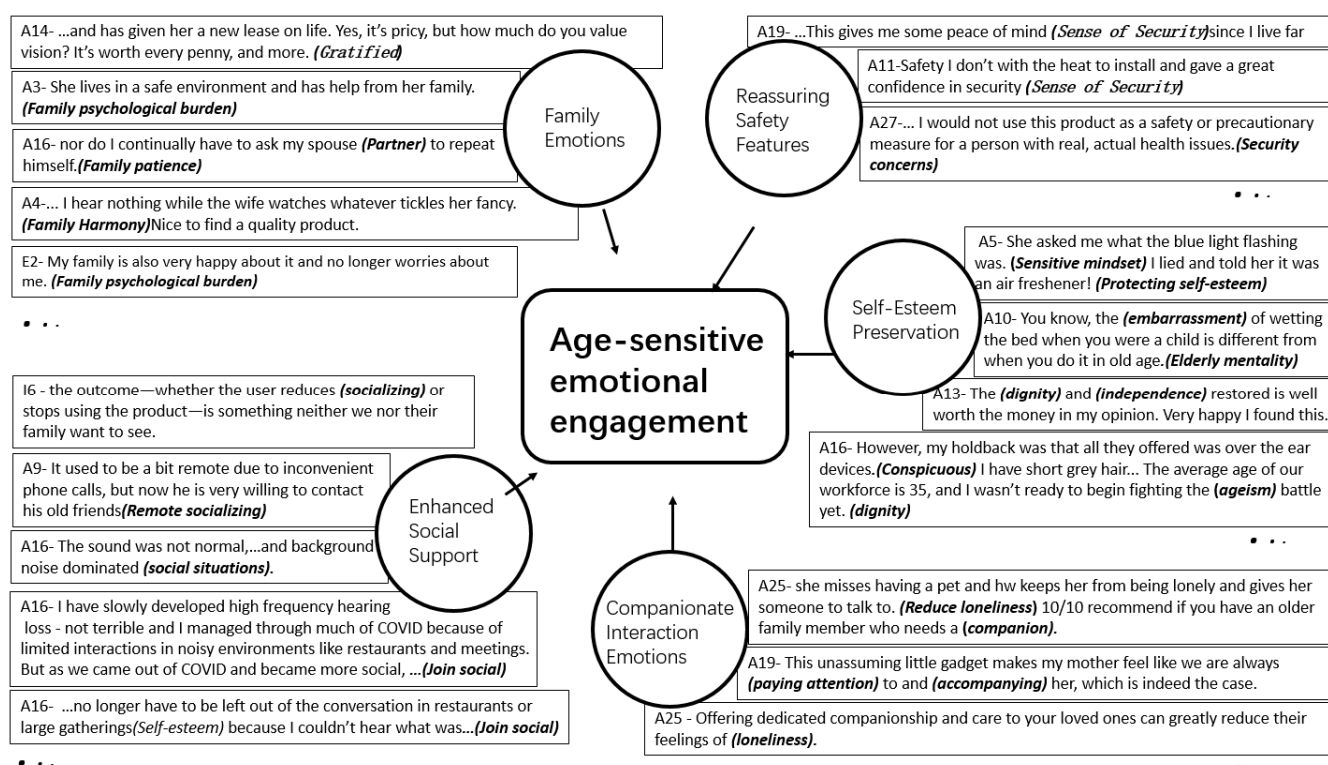


Figure 5. “Age-sensitive emotional engagement” data flow map.

Products like the elderly smart home phone incorporate large family photos for easy one-touch dialing, facilitating communication and fostering emotional connections [55]. These design choices preserve dignity and support essential social engagements, which are crucial for improving the quality of life among the elderly.

4.1.5. Gerontech-Friendly Technology Adaptation

In gerontechnology, balancing usability, availability, learnability, and accessibility is essential to effectively address the unique challenges faced by elderly users (see Figure 6 for details). Gerontech-friendly technology adaptation aims to enhance user experience without overwhelming individuals with unnecessary complexity [56]. For example, devices should feature easy-to-understand interfaces and functionalities that match the elderly's capabilities, such as voice-activated controls or simplified remote controls for those with limited dexterity.

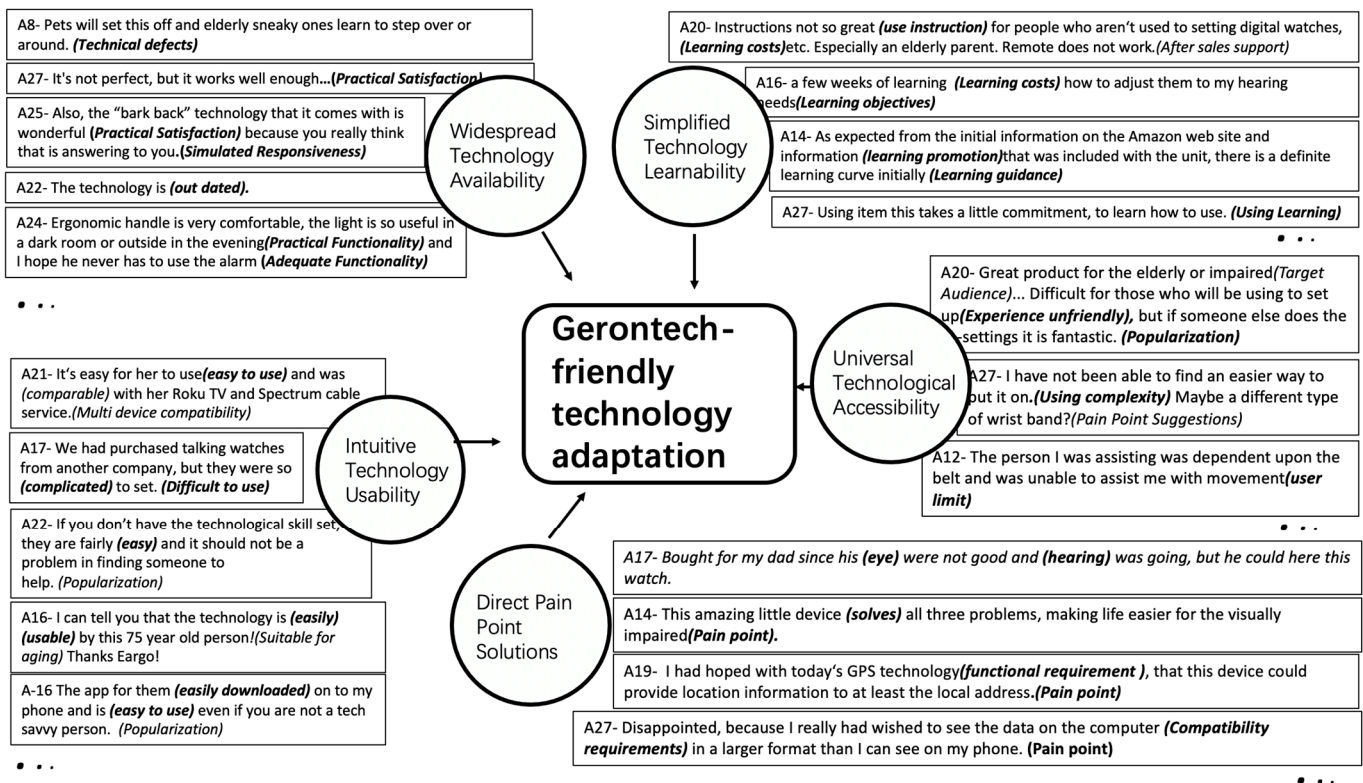


Figure 6. “Gerontech-friendly technology adaptation” data flow map.

Additionally, these technologies must be both accessible and affordable, given the often-fixed incomes of elderly users. The selection of technology should prioritize low learning costs and minimize anxiety related to new devices. This can be accomplished by integrating familiar interaction patterns and avoiding radical technological innovations that do not significantly enhance usability or add value to daily life. By focusing on design aspects such as usability, accessibility, cost-effectiveness, and minimal learning curves, gerontech products can better resonate with the elderly population, ultimately leading to greater adoption and satisfaction.

4.1.6. Senior-Centric Interaction Design

Senior-centric interaction design in gerontechnology enhances usability and accessibility for older adults by accommodating sensory and functional limitations (see Figure 7 for details). Inputs such as voice commands, touch interfaces, and biometric data are tailored for users with decreased dexterity and sensory perception. Outputs like auditory, visual, and tactile feedback provide clear responses. Devices with large tactile buttons and enhanced audio feedback significantly improve usability for seniors with vision or hearing challenges. High-contrast displays and simple interfaces further enhance approachability. Biometric sensors that monitor vital health parameters, such as heart rate and blood oxygen levels, offer valuable data for seniors and caregivers, supporting both preventative health and critical care. Overall, this design approach makes technology safer and easier to use, fostering greater independence and enhancing quality of life.

4.1.7. Integrated Gerontechnology Ecosystem

The integrated gerontechnology ecosystem encompasses a comprehensive support system that includes user support, after-sales service, marketing, packaging, user communities, and seamless device integration (see Figure 8 for details). This ecosystem addresses the challenges elderly users often face with modern technology—such as learning difficulties,

operational complexities, and maintenance issues—enhancing their overall experience and independence.

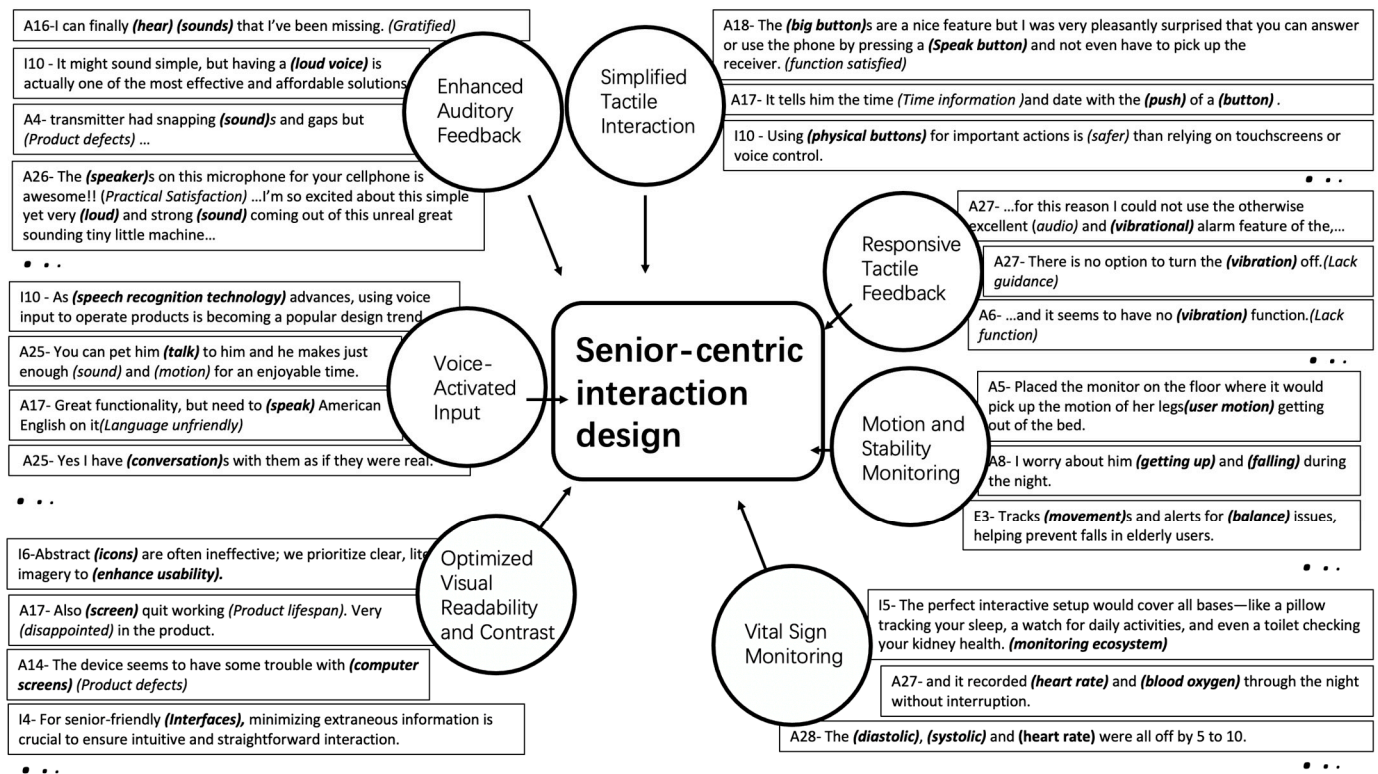


Figure 7. “Senior-centric interaction design” data flow map.

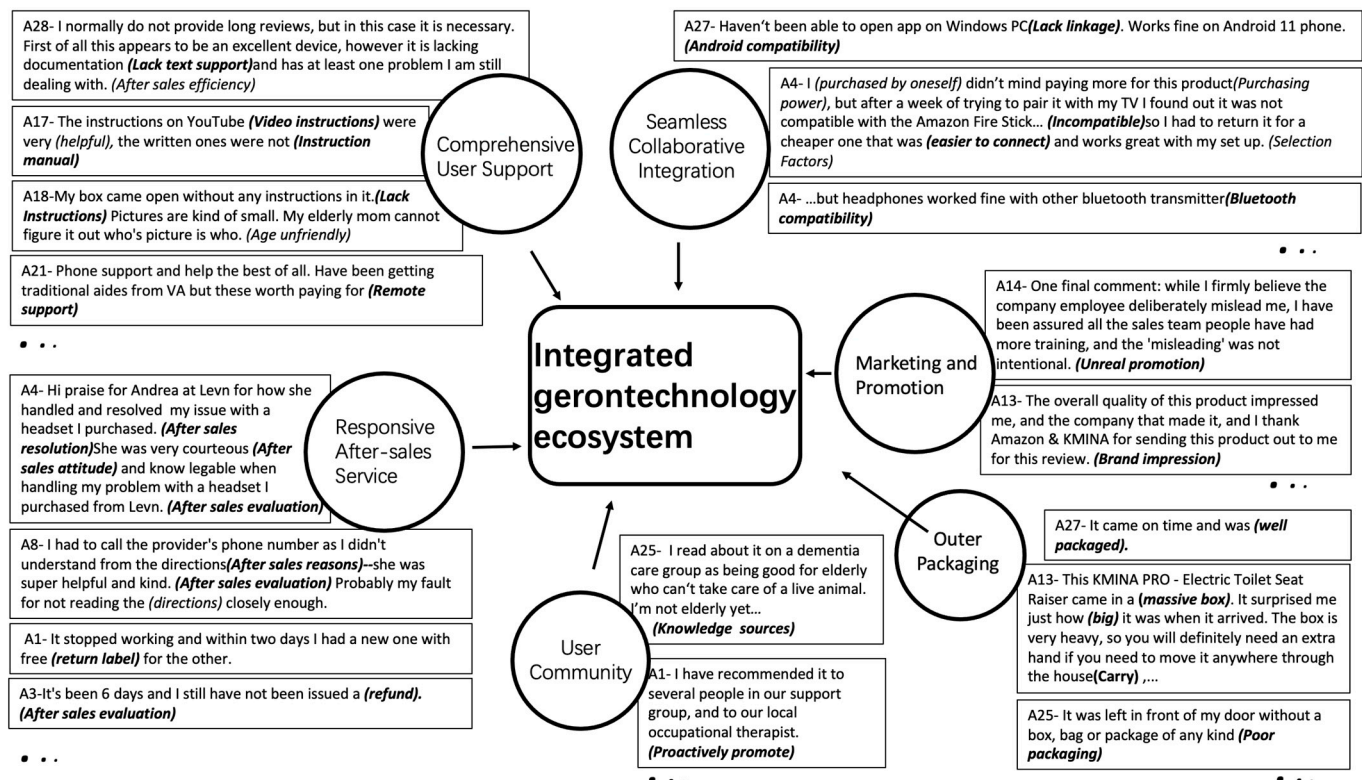


Figure 8. “Integrated gerontechnology ecosystem” data flow map.

4.1.8. Age-Appropriate Aesthetic Design

Age-appropriate aesthetic design in gerontology balances visual appeal and functionality, making products attractive and user-friendly for older adults (see Figure 9 for details). This philosophy incorporates style, color, texture, comfort, and dimensions to enhance daily life. Products should reflect the preferences of elderly users, favoring muted tones like ‘muted champagne gold’ to ensure subtle elegance without stigma. Comfort and usability are crucial; designs must address physical limitations such as reduced mobility and impaired vision, with features like soft textures and large, clear displays. Ultimately, age-appropriate design in gerontechnology should merge functional needs with aesthetics, ensuring these technologies are seen as helpful aids rather than intrusive medical devices.

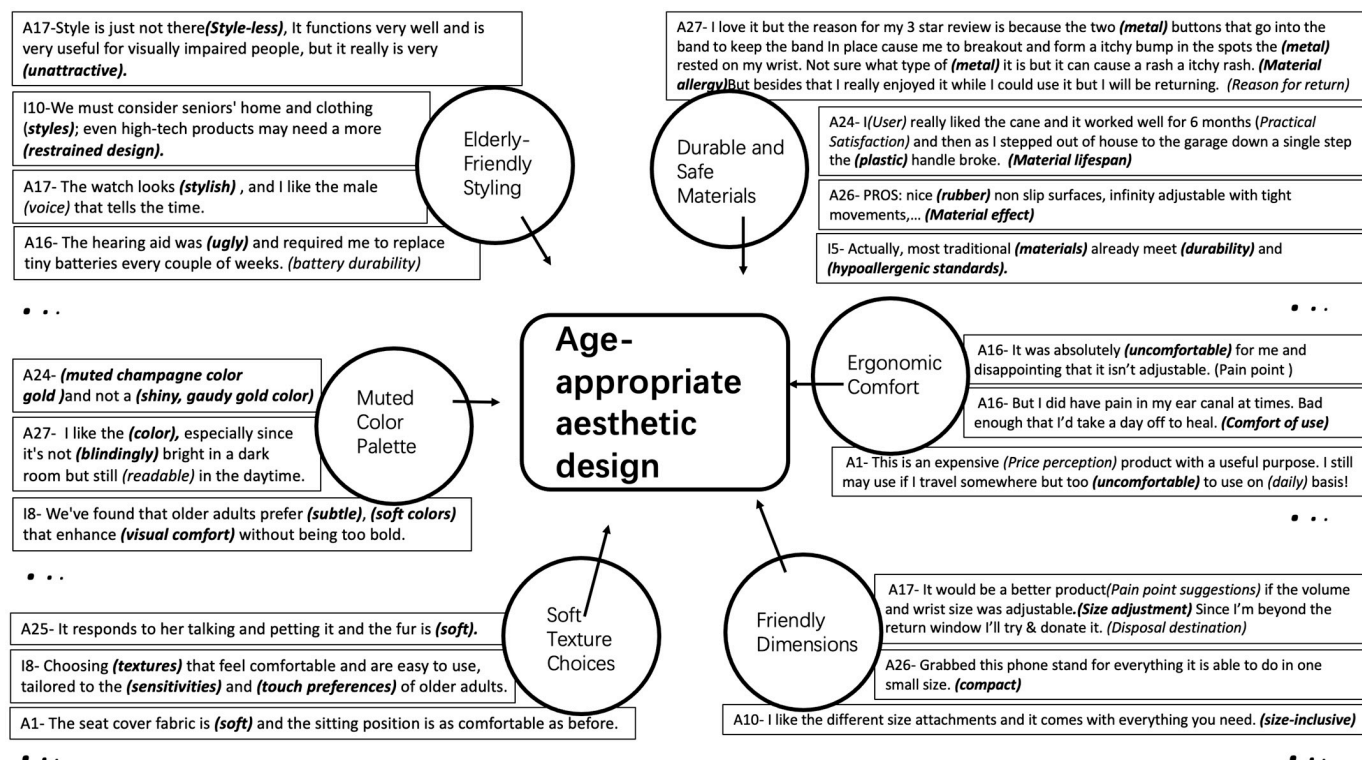


Figure 9. “Age-appropriate aesthetic design” data flow map.

4.2. Theoretical Model

4.2.1. Model Sampling

This section critically reviews several popular macro design models and methods based on the eight key cores identified through Grounded Theory. The discussed models include the Double Diamond design model, Stanford University’s Design Thinking model [57], the Persona model, and Customer Journey Maps (CJMs), among others. Besides these widely recognized theoretical models, the frameworks of design firms such as Australia’s Instructional Design Company [58], Edusquadz [59], and the Nielsen Norman Group [60] are also considered. These frameworks are widely acknowledged for their foundational methods, offering effective guidance for general design challenges. They are particularly known for their structured approaches, fostering creativity and innovation in product development through user-centered methods.

These models each have distinct advantages. For instance, the Double Diamond model provides a conceptual expansion and contraction in the design process, advocating for open research and design and tightening definitions and outputs. The Persona model excels in identifying user groups and needs [61], while the CJM effectively depicts the customer’s

experience, subjective responses, and feelings when using a product or service [62]. Design firm methodologies typically enhance these macro models with market insights, leveraging their unique strengths.

Despite the plethora of existing models to consider, the Design Thinking model was ultimately chosen for its potential adaptability, which stands out. Its iterative and flexible model structure suits the complex requirements of gerontechnology product development, focusing on collaboration between designers and users [57]. It emphasizes integrating real user ideas, feelings, and behaviors into the design, aligning with Grounded Theory's characteristic of inductively deriving experiential generalizations from raw data, thus making it the chosen source for our sampling [63]. The Silver Model for gerontechnology product design integrates the rigorous data analysis of Grounded Theory with the innovative framework of Design Thinking to address the unique needs of the elderly [64]. Grounded Theory plays a pivotal role in our approach, as it allows us to inductively derive insights and systematic design elements from extensive qualitative data collected through user interactions and reviews. This method ensures that our design elements are deeply rooted in the actual experiences and needs of elderly users. Design Thinking complements this by offering a user-centered, iterative design process that involves five key stages: empathize, define, ideate, prototype, and test [57]. This model is particularly well-suited for gerontechnology, as it emphasizes understanding and addressing the real-world experiences of users through continuous feedback and refinement. The iterative nature of Design Thinking facilitates a flexible adaptation of the design process to incorporate new insights generated by Grounded Theory, making it an ideal framework for developing products that are both innovative and highly tailored to the user's needs.

By merging these two approaches, the Silver Model not only harnesses the detailed, user-generated data characteristic of Grounded Theory but also the dynamic, problem-solving capability of Design Thinking. This combination ensures that our design solutions are not only based on solid empirical data but are also adaptable and responsive to the evolving requirements of the elderly, ultimately enhancing the functionality and user-friendliness of gerontechnology products.

4.2.2. Model Explanation

The "Silver Model for Gerontechnology" (see Figure 10 for details) emerges from this critique, offering a comprehensive framework that significantly enhances practical feasibility. Informed by Grounded Theory coding results, this new model presents a bespoke approach to gerontechnology product design, tailored specifically to the unique challenges and needs of this field.

Model Structure: Organized into a circular iterative process, the Silver Model comprises four distinct phases—Discover, Define, Develop, and Deliver. Each phase integrates insights from established methods while prioritizing the unique needs of elderly users. This structure bridges the gap between macro design theories and practical application, aiming to forge a comprehensive framework for developing effective gerontechnology solutions.

Discover Phase: This initial phase focuses on empathetic engagement, where designers explore the environmental contexts and emotional needs of elderly users. Techniques such as direct observation and role-playing are employed to gain deep insights into the multifaceted needs of users, highlighting their unique profiles, emotional expectations, and potential barriers. This exploration establishes a robust foundation for informed design frameworks.

Define Phase: Building on the insights gained from the Discover phase, this stage concentrates on articulating clear design opportunities by aligning the needs of elderly users with potential technological solutions. Its primary goal is to refine product roles

within the gerontechnology realm, using synthesized insights to steer the strategic direction of the design initiative.

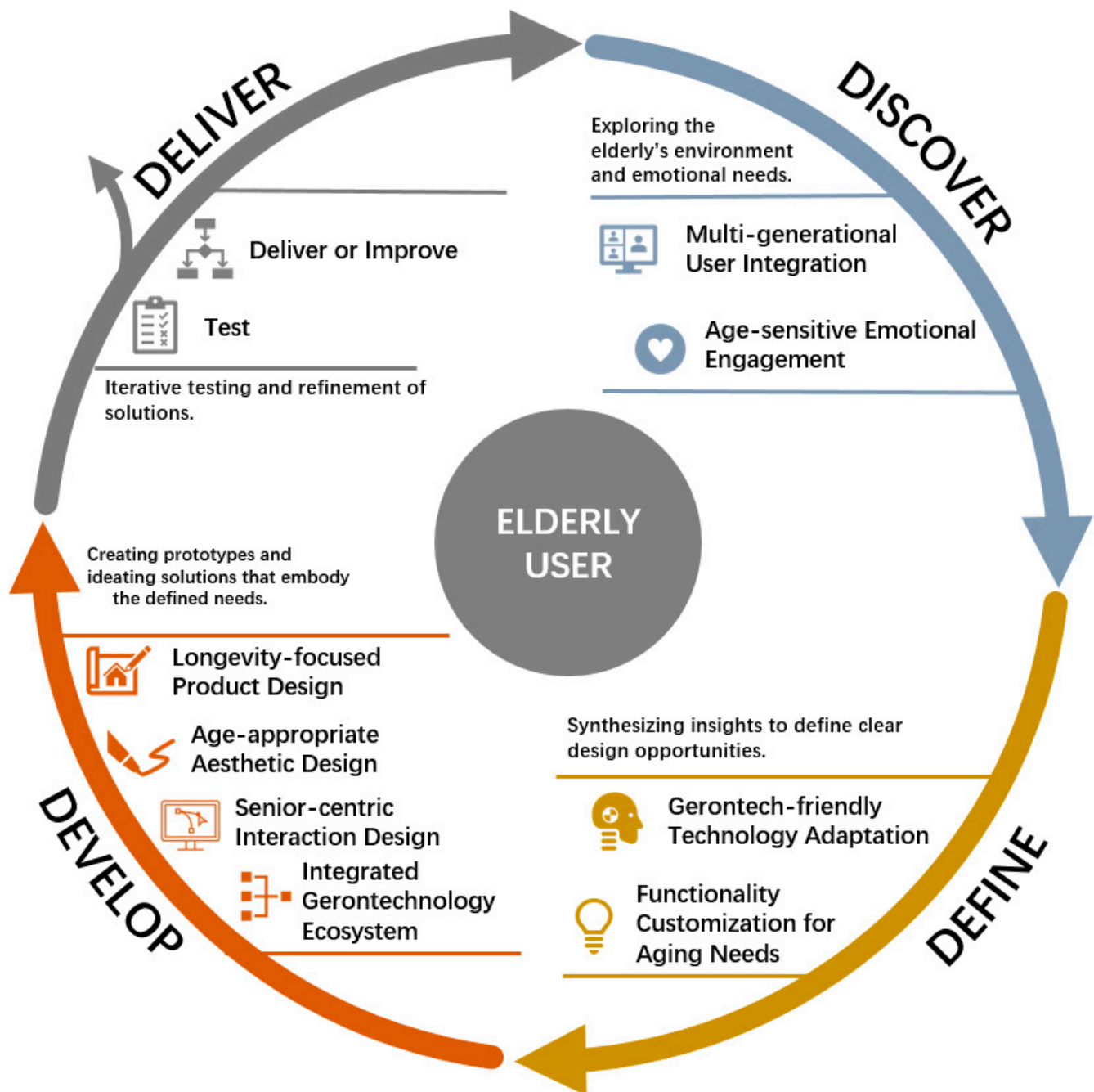


Figure 10. Silver design model.

Develop Phase: Advancing from the defined strategies and identified opportunities, this phase translates concepts into tangible designs and prototypes. It encompasses key elements such as Longevity-focused Product Design, Age-appropriate Aesthetic Design, Senior-centric Interaction Design, and an Integrated Gerontechnology Ecosystem. This ecosystem extends beyond mere product connections, encompassing collaborative linkages between products as well as crucial factors like instructions, after-sales service, and technical support, thus transcending traditional product design boundaries. The final output is a product prototype with comprehensive consideration of multiple systems, ensuring that each element contributes holistically to the user's experience.

Deliver Phase: This final phase entails iterative testing and enhancement of the prototype to ensure it meets expected usability and satisfaction standards. Depending on the outcomes, designs may either progress to finalization or be cycled back into the Silver Design Model for further refinement.

Adaptability of the Model: Given the inherent challenges in technology product design—highlighted by Uysal and Mergen [65] regarding complexity and variability—the model is adaptive, allowing designers to integrate additional practical insights as required by the dynamic nature of real-world applications.

4.2.3. Comparative Analysis of Existing Design Models

A review of existing design models highlights their tendency to offer a macro-level perspective, which, while effective for addressing broad design challenges, often falls short of providing tailored guidance for specific issues. To address this gap, our research introduces the Silver Model for gerontechnology products, a framework that synthesizes foundational design thinking principles with targeted insights derived from Grounded Theory. This hybrid approach enables the Silver Model to offer customized design solutions within a comprehensive and systematic framework, thereby meeting the unique and multifaceted demands of elderly technology design. The model emphasizes extensive user research during its Discover phase and incorporates precise technical specifications throughout the design stages. This rigorous process ensures practical applicability, making the Silver Model particularly effective for platforms like Amazon's e-commerce network, where product diversity and user experience are paramount.

Wynn and Clarkson [66] recognize the inherent challenges of integrating various design models but remain optimistic about the potential of selectively blending insights. While their framework offers a useful categorization of existing models, it faces practical application challenges, particularly in specialized domains like gerontechnology. Our Silver Model addresses this limitation by providing a robust and adaptable framework that enhances the design and development process. By merging macro-level design thinking with the specificity of Grounded Theory insights, the Silver Model delivers a design methodology that is both theoretically sound and practically applicable.

Gai et al. [67] introduce a Quality Function Deployment (QFD) model that leverages social network analysis to refine product design for e-commerce platforms. While this approach effectively translates customer requirements into design specifications, it primarily emphasizes consensus building and lacks a specific focus on the distinct needs of elderly users. In contrast, the Silver Model adopts a holistic approach that integrates broad design thinking strategies with precise design elements informed by Grounded Theory. This method not only enhances the user experience but also significantly improves the design effectiveness of gerontechnology products.

Unlike models that focus solely on individual design elements, such as the Tactile Perception Design Model [68] or the Interaction Design Guidelines [69], the Silver Model offers a comprehensive design approach. It integrates user needs, technological capabilities, and comprehensive design support into a single, unified framework. This holistic integration is essential for developing age-friendly products that address the diverse and evolving needs of elderly users. By providing a well-rounded and practical design framework, the Silver Model offers a more coherent, adaptable, and user-centered approach to the design of gerontechnology products.

5. Discussion

5.1. Company Recommendations

Based on the comprehensive insights derived from our research with the Silver Model, we recommend companies in the gerontechnology sector adopt a targeted strategy to align product development with the key aspects identified as essential for effective gerontechnology design. These aspects include multi-generational user integration, functionality customization for aging needs, gerontech-friendly technology adaptation, senior-centric interaction design, longevity-focused product design, age-sensitive emotional engagement, an integrated gerontechnology ecosystem, and age-appropriate aesthetic design.

Strategic Recommendations for Implementing the Silver Model

Integrate Comprehensive User Feedback: Utilize continuous feedback loops from a diverse demographic of users, including elderly users and their caregivers, to refine products. This feedback should guide iterative design improvements, ensuring the products meet actual user needs while promoting social sustainability.

Adopt a Holistic Design Framework: companies should incorporate the multifaceted aspects of the Silver Model into their design strategies, ensuring that products not only address the functional requirements of elderly users but also enhance their quality of life and social connectivity.

Foster Cross-Disciplinary Collaboration: Develop products through collaborative teams that include experts in gerontology, usability design, and technology. This approach will help create solutions that are both innovative and practical, ensuring products are economically viable and socially relevant.

Conduct Targeted Market Research: Regular, in-depth market analysis should be undertaken to understand and anticipate the evolving needs of the aging population. This research will help companies stay ahead of market trends and better align their products with the demands of elderly users and their ecosystems.

Emphasize Longevity and Sustainability: Focus on developing products that are durable, easy to integrate into existing environments, and adaptable to changing user needs. Such a focus not only caters to the immediate needs of the elderly but also contributes to long-term sustainability, reducing waste and supporting a circular economy.

By integrating these strategies, companies can effectively navigate the complexities of designing for an aging population, positioning themselves as leaders in the silver economy. The recommendations are intended as flexible guidelines that can be tailored to fit each company's strategic goals, operational framework, and sustainability objectives.

5.2. Research Limitations and Future Directions

This study acknowledges several limitations that warrant consideration. While the data are derived from products spanning multiple continents and sourced from e-commerce platforms such as eBay and Amazon, this approach does not ensure absolute generalizability. Furthermore, the qualitative nature of this study, including the use of Consensual Qualitative Research (CQR) and triangulation at each stage, inherently carries a degree of subjective risk [45]. To mitigate this potential bias, we implemented strict validation procedures. Each stage of data analysis involved multiple researchers or reviewers, ensuring diverse perspectives and minimizing the influence of individual subjectivity. The rigor of this approach aimed to cross-validate research findings and reduce individual bias, thereby enhancing the reliability and robustness of the conclusions. Despite these measures, the subjectivity inherent in qualitative analysis remains a persistent challenge.

Future research could adopt more diversified and multi-method approaches. Combining quantitative validation techniques, such as large-scale user surveys or structural equa-

tion modeling (SEM), could empirically examine the relationship between the “Eight Aspects” and design effectiveness. To enhance the generalizability of the model, future studies could also incorporate data from regional e-commerce platforms (e.g., Taobao or Rakuten) to ensure broader contextual applicability.

6. Conclusions

As gerontechnology products evolve, a significant gap remains in their design—the absence of objective and systematic models—which results in the loss of essential knowledge. This study develops the Silver Model, a specific guiding design model informed by user reviews and insights from expert designers across various e-commerce platforms, including Amazon and eBay. Aimed at enhancing the silverization process of gerontechnology products, this model transitions from a singular design approach to a comprehensive, multifaceted system, making tacit design thinking explicit within a structured framework.

Research findings from e-commerce feedback and interviews with professional designers reveal that key concepts converge around eight essential aspects for the silverization design of gerontechnology products: multi-generational user integration, functionality customization for aging needs, gerontech-friendly technology adaptation, senior-centric interaction design, longevity-focused product design, age-sensitive emotional engagement, integrated gerontechnology ecosystem, and age-appropriate aesthetic design. These aspects were developed through systematic Grounded Theory coding and represent a comprehensive approach to addressing the unique needs of elderly users. It supports the creation of products that enhance both the quality of life and social sustainability of elderly individuals, enabling them to live more independent, connected, and fulfilling lives.

The Silver Model introduces a novel perspective, urging designers to adopt a more comprehensive and meticulous approach in developing gerontechnology products, ensuring that design solutions effectively meet the complex needs of elderly users. Unlike existing models like “Design Thinking,” the Silver Model integrates specific gerontechnological considerations, enhancing its applicability and effectiveness in this specialized field.

Silverization design research can significantly enhance the well-being of older adults and help society address the challenges posed by aging. This study exemplifies the integration of theory and practice, providing a foundation for future studies and design innovations that improve the technological experience for older adults. By emphasizing social sustainability, the Silver Model encourages researchers and designers to focus not only on meeting the immediate needs of elderly users but also on fostering a more inclusive and sustainable society.

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

Appendix A

Table A1. Research product list.

	ASIN and NAME	DISPLAY
A1	B08C4YZ25R Portable Smart Rising Seats—400lb Capacity Chair Lift Assist for Seniors, 100% Stand Assist Chair Lifts for Elderly, Sit to Stand Lift Seat	
A2	B075NT5WHV SkyAngel911FD—Mobile Cellular 4G—NO Monthly FEE—911-2-Way Voice—Waterproof Alert Phone—Automatic Fall Detection (Blue)	
A3	B087JXZ7ZR Premium Locking Automatic Pill Dispenser 28 Slot Electronic Medication Organizer (Clear and Solid White Lids)	
A4	B0CJMMWTWS LEVN Wireless Headphones for TV Watching, TV Headphones Wireless for Seniors with TV Transmitter Charging Base, Hearing-impaired, No Audio Delay Bluetooth Headphones, Plug and Play, Gifts for Elderly	
A5	B096WBQWBX Upgraded Version Bed Sensor Alarm and Fall Prevention for Elderly/Dementia and More, Caregiver Pager Motion Sensor Alarm with 5 Volume Level (1 Caregiver Pager + 1 Sensor)	
A6	B0BR3JPX65 Elderly 4G GPS Smart Watch Real-Time Tracking Two-Way Phone Call GPS Tracker Waterproof Touchscreen Watch with Camera SOS Emergency Alarm Pedometer Tracker Watch Christmas Birthday Gift (Black)	
A7	B0C9WLDQSJ Magnifying Glass with Light Reading Gifts—Rechargeable Led Page Magnifier 5X Mothers Day Fathers Birthday Gifts for Mom Dad Grandma Grandpa Seniors Elderly Book Lovers Handheld Vision Aids	
A8	B06XMY43G8 Smart Caregiver Cordless Floor Mat Pressure Pad with Economy Cordless Alarm (No Alarm in Patient's Room), Gray, 24" × 48	

Table A1. Cont.

	ASIN and NAME	DISPLAY
A9	B0CQQWJ7WR 4G Volte Big Button Cell Phone Unlocked for Seniors Big Buttons LTE Phone for Elderly & Kids, Clear Sound, SOS Button, Convenient USB-C & Charging Dock, Talking Numbers, Black	
A10	B07934MXY9 Opro9 Smart Diaper, Bedwetting Alarm for Seniors, Smart Wearable Wet Diaper Alarm Sensor & Real-Time Movement Tracking Monitoring App, Instant Alert Notification Reminder, Prevent Elderly Diaper Rash	
A11	B0BZYCNBSG Bed Rails for Elderly Adults—with Motion Light & Storage Pocket, Bedside Assist Bar for Seniors & Surgery Patients—Medical Bed Handles w/Extendable Height & Lenth Fit Any Bed	
A12	B0BHF3797V Gait Belts Transfer Gait Belt for Seniors with 7 Handles, Gate Belt for Elderly Lift Belts with Quick Release Buckle Anti-Slip Function Prevents Patient from Shifting More Effectively	
A13	B0BQJR1JGC KMINA PRO—Electric Toilet Seat Lift with Ergonomic Handles, Powered Toilet Seat Lifter for Seniors, Robust Raised Toilet Seat with Handles for Elderly, Electric Toilet Seat Riser Height Adjustabl	
A14	B07H31SBMW OrCam MyEye Pro—The Most Advanced Wearable Assistive Device for the Blind and Visually Impaired. Featuring Smart Reading, Face Recognition, Color & Product Identification	
A15	B07QRQSFWW 3.5 Inch Electronic Portable Video Aids Digital Magnifier Handheld Low Vision Reading Magnifier for Students, The Elderly in Reading, Newspapers, 2X-25X Zoom, AV /TV Output (Black)	

Table A1. Cont.

	ASIN and NAME	DISPLAY
A16	B0BSHCNP5W 7 Self-Fitting FDA-Cleared OTC Hearing Aids—Most Advanced Model, Virtually Invisible CIC, Rechargeable, Lifetime Customer Support	
A17	B01D9ROI7G English Atomic Talking Watch, Easy to use for Seniors Blind Men Women, Loud Talking Watch with Sound for Vision Impaired, Watches for Elderly Women, Blind People Products 1095	
A18	B0CGVM1TBK Landline Phone, Big Button Phone for Seniors, Telephone Can One-Touch Dialling with 9 Piction, Suitable for People with Vision Disorders/Hearing Damage, Corded Phone Can Be Used for Home	
A19	B072LKRLH9 SkyAngel911FD—Mobile—4G -Cellular—NO Monthly FEE—911-2-Way Voice—Waterproof Alert Phone—Automatic Fall Detection	
A20	B083YZ6K66 Véfañ Newest, Dementia Clock 2.0 with Auto DST, 20 Custom Reminders, Day Clock with Sun/Moon Icons for Memory Loss, Alzheimer's, 7'' with Remote & HD Picture Frame	
A21	B0CR5S1BCN Big Button Universal TV Remote for Seniors—2-Device Control—Easy Setup & Programmable Favorites Management, IR Devices—TV, Cable, & Set Top Boxes (STBs) (New Version)	
A22	B0CKW3SXPQ iGuerburn Dementia Music Player for Elderly, Memory Loss, Vision Impaired Patients, 32GB Simple Mp3 Box with USB, Alzheimers Products Gifts for Seniors Easy to Use—Blue	

Table A1. Cont.

	ASIN and NAME	DISPLAY
A23	B0CL5XZY79 Electric Spin Scrubber, Cordless Shower Cleaning Brush with 7 Replaceable Heads, Detachable Long Handle for Bathroom, Floor, Tile, Kitchen, Ideal Gift for Elders	
A24	B09VGNDMGN Smart Alarm Walking Cane for Men & Women, Telescopic and Adjustable Walking Sticks for Seniors, USB Direct Charge, with LED Light, One Cane for Three Purposes, Light and Stable	
A25	B00CWY1U74 JOY FOR ALL—Freckled Pup—Brown and White Soft-Touch Coat—Realistic and Lifelike Interactive Companion Pets	
A26	B0BRXLRLG6 Gifts for mom Coolest Women Best Gifts for Elderly-Valentine's Day Christmas Fathers Day Phone Stand Kitchen for Desk with Speaker Gifts for Men who Have Thing Useful The Stocking	
A27	B094JG4JD7 Wellue O2 Pulse Oximeter with Smart Reminder Blood Oxygen Saturation Monitor for SpO2 and Heart Rate Tracking Continuously, Bluetooth Finger Ring with Free APP & PC Report	
A28	B071LHGZVR CONTEC ABPM50 Handheld 24hours Ambulatory Blood Pressure Monitor with PC Software for Continuous Monitoring NIBP USB Port with Three Cuffs	

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