Research on Inclusive Design of Kitchen Products for Aging Populations Based on Universal Design Principles

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Abstract

An ageing population is a demographic trend of the twenty-first century, with a kitchen being recognized as a key setting in successful aging in place. Traditional kitchen products may have not been effective in helping the elderly due to a lack of personalization or stereotyping involved in the design process. This study proposes an approach towards developing an efficient tool for applying the principles of universal design into kitchen products designed for elderly people through implementing a multi-method approach, comprising four interconnected stages: user research, analytical synthesis, design practice, and systematic evaluation. Semi-structured interviews and contextual observations were conducted among 20 elderly individuals and 10 of their relatives living in urban areas in China. Qualitative data collected via semi-structured interviews and contextual observation were then analyzed in accordance with hierarchical task analysis combined with user journey mapping techniques in order to reveal the physical, cognitive, and emotional aspects of product usage.In conclusion, an Inclusive Kitchen Product Design Framework has been developed, showing how the principles of universal design should be applied across three interacting levels of physical, interactive, and emotional experience. Three different kitchen product concepts were created as a proof of concept for the Inclusive Kitchen Product Design Framework: an inclusive induction cooktop, a lift-assisted storage system, and a multi-grip electric kettle. According to a formula combining interactions between the seven principles, their design solutions received composite inclusive design scores of 3.87, 4.12, and 3.65, respectively. It can be concluded that interactions between the seven principles do not simply add but multiply, with cross-level interactions providing greater value compared to being superior in all levels.

Keywords

Universal Design Principles; Inclusive Kitchen Product Design; Aging Populations; Design Framework; Multi-Generational Households.

1. Introduction

1.1. The Global Aging Trend and the Role of Kitchen in Aging in Place

The growing number of elderly people is the major problem of contemporary society, which alters the ways of providing care and accommodation. Given the fact that life expectancy is constantly increasing while the birth rate decreases significantly, the design industry experiences new responsibilities regarding the participation of disabled individuals in the design process. Specifically, elderly people prefer living in their homes rather than relocating to institutions for various reasons, which leads to the phenomenon called aging in place [13].This concept means much more than just emotional attachment to the house; instead, it denotes people's desire to maintain their autonomy, engage in social interaction, and perform activities independently.As far as aging in place is concerned, the kitchen can be viewed as one of the most significant places since in the kitchen older people perform numerous tasks,

such as preparing meals or working with various appliances. With the advent of home automation technology, kitchen appliances have drastically changed due to the growing need in them in those countries which have experienced particularly rapid aging, such as China [15].It is necessary to note that the creation of innovative products for supporting elderly people's activities in the house environment provides many possibilities. At the same time, the widespread application of these assistive devices is often hindered by a series of usability problems [17].In conclusion, it is essential to say that the kitchen plays a vital role when it comes to aging in place.

1.2. Problem Statement: Design Gap for Aging Populations

Despite the increased interest in the issue of designing for older individuals, the current gap between the physical and cognitive capacities of older users and the products currently available on the kitchen market remains rather substantial. In ergonomic research conducted on kitchen products, it is noted that older users have a high probability of injury, tiredness, and difficulty performing their activities due to the kitchen products used, and the issue is not resolved via product design [19].In terms of the current kitchen products, there are two strategies that fail to meet the needs of the elderly population. On the one hand, some researchers argue that one-size-fits-all products can be employed by any user regardless of their age and individual characteristics, while others propose developing specific "senior" products, thereby potentially stigmatizing their target audience.

One may regard universal design as a theoretical basis of the problem under consideration, since universal design involves creation of conditions for non-segregation and success for people throughout their lives, when accessibility will be a feature that benefits all people, rather than minorities [21].On the other hand, the theory of inclusive design, being based on diverse abilities and emerging from the UK, offers even more theoretical tools for addressing aging within the context of design [1].Still, one should say that it is difficult to implement these general concepts in terms of product design related to the kitchen because there are certain difficulties associated with implementation of the idea of inclusivity in the discussion about the built environment [4].Actually, one may assume that it is not the absence of theoretical basis that is the problem, but rather an absence of relevant frameworks for implementation of the theory into practice.

1.3. Research Objectives and Paper Structure

Given this void, it has become necessary for this study to explore avenues that may help convert the seven principles of universal design into strategies that may aid in designing kitchen products catering to the needs of aging users. The emergence of a new generation of models of inclusive kitchens has provided insight into how factors like space, technology, and emotions interact to affect the experience of aging users. However, these models concentrate more on kitchens than products found within them [7].The concepts of inclusion, diversity, and equity in the context of built environment played a major role in forming the framework of this research; however, modification is needed in their use in this case [2]. The conversion of the universal design principles for application in kitchen furniture is feasible via case studies that confirm its feasibility; however, only kitchen furniture was considered and not other kitchen products available for the use of elderly persons [9]. Finally, a medical device design model has become the basis for the development of this research methodology; however, it concerns medical devices and not kitchen products [22].

Building upon the previous body of knowledge, taking its weaknesses into account, the research intends to address the following three objectives, which are interrelated. Firstly, it aims to explore the requirements of elderly consumers with regard to kitchen activities through using the approach that combines literature review with user studies. Secondly, the research is focused on developing a framework of inclusive design of kitchen products based

on the universal design approach that would transform the seven universal design principles into practical guidelines for the products under consideration. Lastly, the research seeks to validate the proposed model with the help of three designed and evaluated product prototypes. As a result, the anticipated outcome of the research will be closing the gap between the theoretical foundation of universal design and its practical application to kitchen products, i.e., developing the conceptual framework of aging-centric inclusive design. The present paper will include five chapters.

2. Literature Review

2.1. Universal Design and the Seven Principles

Universal design has been explained by a group of experts headed by Ronald Mace of North Carolina State University from the year 1997 onwards. Seven principles that are to be followed in order to make sure the effective designs of products as well as environments in respect of people with varying levels of ability have been developed by the group. These include: (a) equal use; (b) flexible use; (c) simple and intuitive use; (d) perceptible information; (e) tolerance for error; (f) minimal effort; and (g) adequate size and space for use. This covers several different areas in the user experience, thus enabling the notion of usability to be understood as a multidimensional, not a unidimensional, construct.

The difference between universal design and other accessibility approaches lies in the fact that it does not consider people with disabilities or the elderly as exceptions to the rule who require special treatment. It relies on the concept that human beings exist as a range of abilities rather than a distinction between normal and abnormal individuals. Such an understanding will have profound implications for product design because, instead of designing for particular groups of users, the artifacts should cater to everybody, irrespective of their specific capabilities. Universal design is especially relevant when applied to seniors, as they cease to be seen as an edge case but become the baseline against which usability and product quality are measured.

While often used in the realm of designing products, the use of these seven design principles is not evenly spread across the various types of products available. While the application of design principles, according to these seven principles, has been widely utilized in some product lines, others still remain under-utilized. Kitchen products, in particular, are one of the areas that require a closer look into the application of these seven principles.

2.2. Inclusive Design and Its Relationship to Universal Design

The concept of inclusive design was implemented in the United Kingdom in the 1990s, being theoretically different yet practically similar to the issue of designing products for different categories of people. The development of inclusive design theory in the United Kingdom has brought the focus on diversity and understanding that usually one single product cannot meet all the requirements of all customers [1].Universal design aims at making its universality available for everyone. However, inclusive design implies that the number of products should be more than one to address all possible cases of usage. The distinction goes beyond terminology and concerns significantly the issues arising from selecting one of many opposing criteria in designing a single product.

In fact, the practical importance of the above-discussed duality becomes particularly evident in the context of studying the elderly. Within the framework of universal design, the kitchen product designer attempts to generate designs that are equally convenient for use by both young people and seniors. In the context of inclusive design, the same designer will introduce modular and adjustable components so that products could be adjusted according to the needs of different consumers without designing special products for the elderly. Considering

the current debates concerning the inclusion of inclusive design in the construction industry, one can note that the discussion should not focus solely on functional accessibility but should include relational aspects of products as well [4].

However, both traditions work together in their implementation in the sphere of aging and design studies. While universal design offers the theoretical foundation necessary for evaluating designs, inclusive design draws attention to the diversity of the products and dignity, taking into account the social consequences of the products. The present study incorporates both traditions, where the seven principles of universal design are considered the primary theoretical framework, and dignity is viewed from an ethical perspective.

2.3. Aging Populations and the Characteristics Relevant to Kitchen Product Design

In designing an interface for the aged population, there should be consideration of the effects of aging on the skills that dictate the usage of daily objects. There are several effects of aging on one's physiology including weaker grips, rigid joints, deteriorating vision, and slow reactions. Not all the elderly population is affected by aging in the same way, since there is much variation in this community. One aged individual in fine health might actually perform better than a middle-aged individual, but another individual of similar age but who suffers from several ailments would definitely experience greater difficulty.

Moreover, the interrelations between physiological and cognitive changes make it even more difficult for a person to use a product. Some of the general features of aging people include slow processing, lower concentration skills, and difficulties adapting to new devices. An appliance for cooking that uses fast pressing of buttons during different intervals is likely to test both physical and cognitive skills of an individual. Thus, it will not be sufficient to assess the usability of the device from the point of view of either of these factors alone.

Nonetheless, psychological and emotional effects of aging are important, although they do not receive enough attention when it comes to design from an engineering perspective. Indeed, in many cases, people of old age tend to shy away from products that are clearly meant for them because such products may make them feel helpless and less valued. This is an important aspect of designing products for elderly consumers. A product designer must take into account both physical and psychological needs of the elderly without stigmatizing them. This follows the tenets of universal design.

2.4. Current Research on Inclusive Kitchen Product Design and the Remaining Gap

Several different streams have been formed in the scientific research concerning the design of kitchens for older adults. The first stream considers the kitchen as an ecological system, offering multiple models that include all the factors related to space, technology, emotions, and security within a single design system [7]. This research has broadened the vocabulary associated with kitchen design and shown that the user experience is based on a multifactorial combination of different factors, not only one specific aspect of kitchen design. The second research stream concerns the issue of kitchen furniture design, giving several examples that demonstrate the possibility of implementing universal design theory in the design of kitchen furniture, which includes, among other things, height adjustment and convenient storage compartments.

Though much effort has been expended on this, a theory that encompasses all universal design principles with regard to kitchen appliances designed for use by elderly individuals has yet to be developed. In this sense, the empirical work conducted on universal design principles seems to examine only certain specific universal design principles and fails to elaborate on how they interact during the design process. In addition, whereas considerable

amount of research exists about kitchen design in the Western world, little attention has been paid to cultural behavior associated with China's kitchen space such as communal cooking and space limitation.

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3. Data and Methods

3.1. Research Design and Mixed-Methods Approach

The research methodology used here includes a mixed methods approach. This approach entails a combination of both quantitative and qualitative approaches. With regard to using kitchen products among old people, there is a range of measurable aspects such as the rate of performing various tasks and error rates alongside some very subjective measures such as the feeling of competence, security, and dignity among others. This makes it necessary for one to integrate the two in the most effective manner possible. Previous empirical research regarding age-appropriate design of smart homes' interface had already created a precedent in this case through structuring behaviors coupled with interpreting them [11].From the above and with specific focus on kitchen items, it is evident that the present research involves investigation of three particular samples. These include appliances for cooking, storage and retrieving devices, and countertops small appliances. There are four main components of the design in this case, which include research framing, user research, design synthesis, and evaluation.

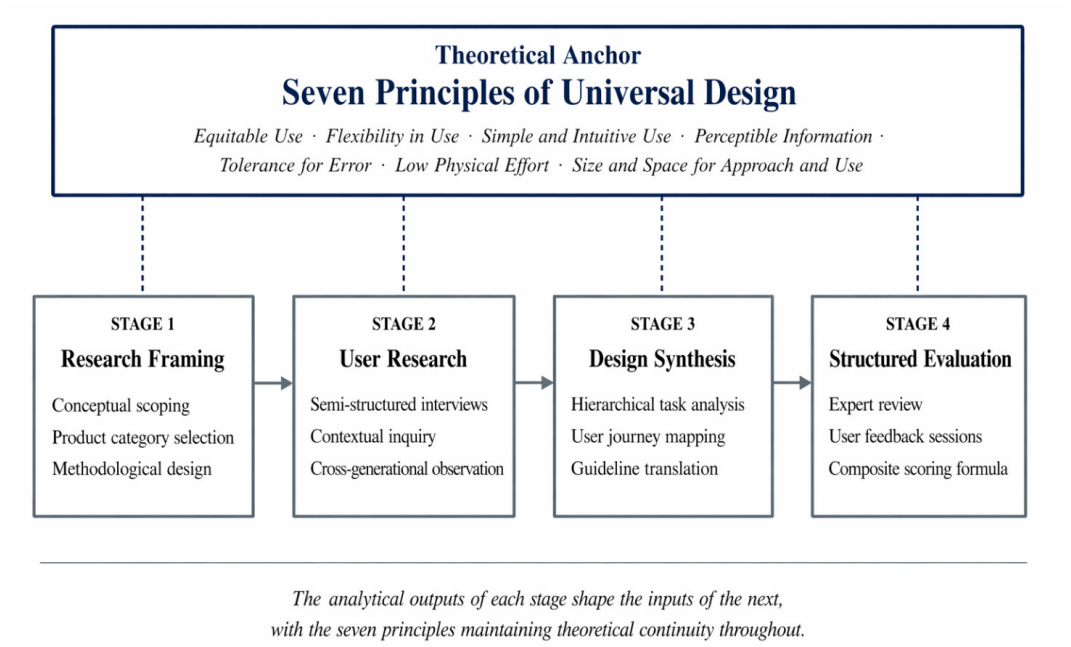


Fig 1. Overall research framework showing the four-stage methodological flow and the unifying role of the seven principles of universal design.

It is critical to clearly state how all four phases interact because the outcomes of each phase will serve as input for the following phase. If this step is not done, the whole methodology will just look like a sequence of actions that have nothing to do with any investigation process. As one can see from the picture below, our research model is based on the universal design principles that become the common thread for the whole research and analysis process. Hence, no matter what comes out of the user research, design synthesis, or evaluation phases, it will always be grounded by theory.

Designing the framework is the first methodological novelty in this research, marked by the introduction of the concepts of universal design, not to assess something but rather to structure the collected data from the very onset of its collection. The use of the concept of universal design in this context introduces the novelty of its application in this research, laying the foundation for future user research.

3.2. User Interviews and Contextual Inquiry

For conducting user research, a technique combining semi-structured interviews with contextual inquiry in the kitchen was chosen. The reason for selecting this technique was not based on the practical aspect but rather on the substantive one, since using kitchen appliances and tools involves space, sequence of actions, and sensory experience which cannot be replicated in laboratory conditions. In trying to abstract the user from the environment in order to evaluate the interaction with the product, one would be taking away the key data that is required for developing inclusive design solutions. The protocol for interviews included seven principles accompanied by an interpretation of each principle posed in two to three questions, prompting the user to provide real-life examples of when these principles did and did not take place.

The participants were twenty elderly persons, above sixty years old, and ten young individuals who usually cook alongside the older people within the same kitchen in the same household. The reason for selecting such samples is that there exists a cultural belief that a Chinese household kitchen is generally shared by different generations rather than being used solely by an individual. The interviews took between forty-five to sixty minutes, aided by fieldnotes and photographs. Among the main challenges faced while researching older adults is finding ways to elicit valuable information about them without making them passive subjects. Research carried out on collaborative designing of smart home interfaces indicated that with adequate application of participatory methods, it is possible to make older adults collaborators rather than informants [16]. This study extends the idea further by considering the elderly participants' narration of their routine as a form of knowledge claim.

3.3. Task Analysis and User Journey Mapping

The application of Hierarchical Task Analysis and User Journey Mapping approaches has been undertaken to assess the obtained data by means of interviews and observation. The joint application of these methodologies within the same phase of analysis is another innovation associated with this study. In case of Hierarchical Task Analysis, the process of cooking is broken into sub-tasks, which allows detecting the points where the cognitive and physical loads are too high for older users. As for User Journey Mapping, it depicts the way the kitchen task unfolds in time, indicating its painful moments and opportunities. These methods of research involve different levels of analysis. While in previous studies only one of these methods was applied, the joint application allows obtaining a two-dimensional analysis framework.

The relationship between both of these approaches is described in Figure 2 below. In the first place, the structural approach will yield data that would indicate the places where the person has experienced overload, either physically or mentally. Nevertheless, the reason why such

places have been determined as stress points for the elderly will not be explained. In the second place, the experiential approach will yield data related to those experiences; nevertheless, the reason why such places have been determined as stress points will not be known.

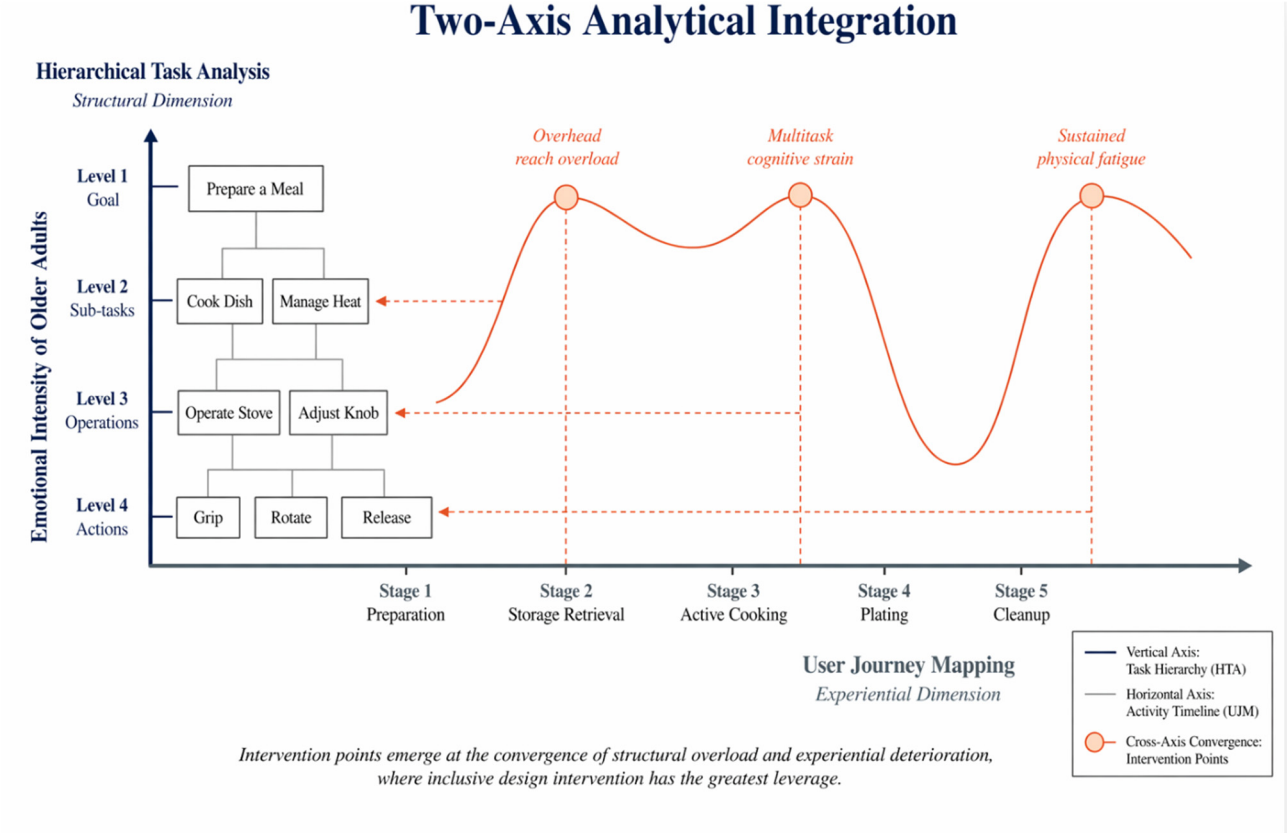


Fig 2. Two-axis analytical integration combining hierarchical task analysis with user journey mapping for older adults' kitchen activities.

The intervention points produced from the above process not only have structural validity but are also relevant to experience and Figure 2 illustrates the same. These intervention points become the input for the design synthesis process mentioned below.

3.4. Design Practice and Evaluation Methods

During the stage of synthesis design, all the intervention points which had been identified in the earlier phase were designed into three different designs of products. However, what is significant is that each product design had to address several principles of universal design rather than only being concerned about a particular universal design principle. This is due to the fact that, during user testing, it was realized that these universal design principles could not work independently of each other.

However, the next step of evaluating this interaction needed to be performed in a manner that would enable the quantitative inclusion of the non-independent nature of data. Systems that use the methods where equal or even linear weighting schemes are used are not enough since it does not consider the interaction aspects. The same realization was made during earlier work on developing other evaluation methods for evaluating interactions between elderly people and home appliances [14].Considering the interaction effect, the scoring scheme adopted in this study takes into account both the direct and interaction factors. Hence, the scoring method becomes:

$$S = \sum_{i=1}^{7} w_i \cdot s_i + \lambda \sum_{i<j} \alpha_{ij} \cdot s_i \cdot s_j$$

where $S$is the composite inclusive design score, $s_i$is the score assigned to the i-th principle on a five-point scale, $w_i$is the expert-calibrated weight of the i-th principle subject to $\sum_{i=1}^{7} w_i = 1$, α_{ij} is the empirically observed interaction coefficient between the i-th and j-th principles taking values in [-1,1] to capture both reinforcement and tension, and $\lambda$is a scaling factor that controls the relative contribution of the interaction term. The inclusion of the interaction term is not a mathematical ornament but a direct response to the user research finding that certain principle pairs consistently reinforce one another, such as low physical effort combined with tolerance for error, while other pairs can generate design tensions when pursued simultaneously, and capturing this structure quantitatively allows the evaluation to reflect the true experiential complexity of inclusive kitchen design rather than masking it behind a simple summation.

4. Results

4.1. User Needs in Kitchen Activities: A Cross-Generational Perspective in Chinese Families

From the analysis of both interviews and observations, a cluster of recurring user needs could be identified as being associated with three interrelated dimensions of kitchen utilization. The first identifiable dimension pertains to physical necessities, where older individuals found issues related to their inability to perform actions that involve handling, lifting up over their heads, and reaching down to retrieve things from storage cabinets. Lack of strength in hands turned out to be an especially challenging factor in cooking activities where individuals struggled with opening packets, turning knobs on stoves, and handling gadgets, leading to fatigue or inability to complete the task altogether. Cognitive necessities formed another dimension, which was often combined with the previously mentioned one. Multitasking, defined as performing multiple activities in the kitchen at once such as handling boiling water while at the same time using the fan or a timer, posed a challenge, especially when it was combined with the necessity to interact with gadgets that required fast responses from the participant.

Yet another no less important finding is related to the space of Chinese kitchens in the family settings. These kitchens were quite small, taking up the area smaller than six square meters, while at times of preparing food more than one cook was present in such kitchens. In other words, this situation calls for development of those products that should address both the needs of individual senior people as well as those activities which should be done collectively by various generations in small spaces. Another no less important finding in terms of intergenerational collaboration involved the fact that ten young people from families did not engage in negotiation with their seniors regarding the accomplishment of certain difficult tasks. Specifically, the young people engaged in opening higher shelves as well as operating the interface without any prior agreement. Therefore, these young people helped to solve the problems, yet made senior people loose control over the activities. Such aspect cannot be easily measured in terms of ergonomic evaluation.

Using the information gathered, a user journey map as well as pain points distribution map has been made. The user journey map describes the overall meal preparation process by dividing it into seven stages and identifying the stresses in each stage both physically, mentally, and emotionally. As can be observed in Figure 3, it is clear that the stages which

involve retrieving the food ingredients from storage, cooking the meal, and clearing up after the meal have substantial physical, mental, and emotional stress. On the contrary, stages such as cutting and plate have less stress but some emotional friction.

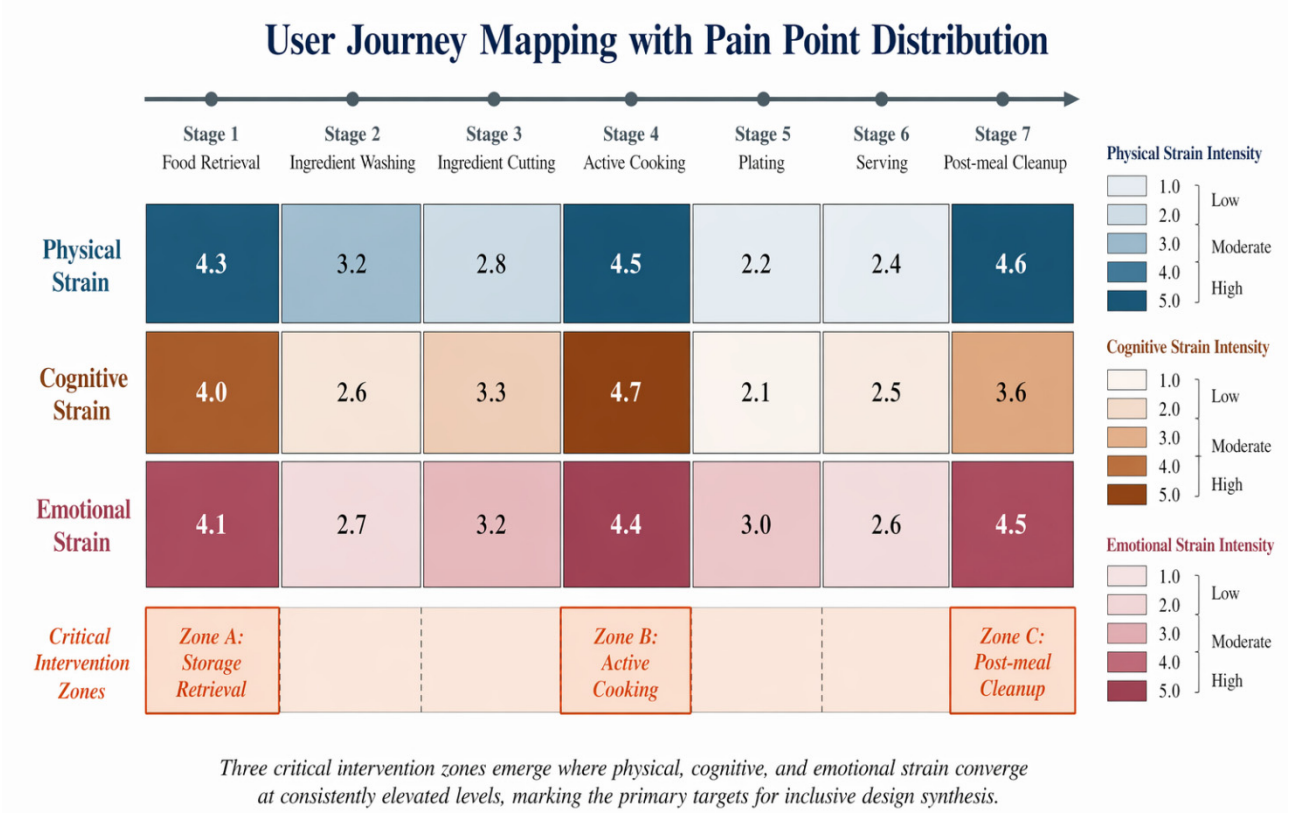


Fig 3. User journey map and pain point distribution for older adults' kitchen activities across physical, cognitive, and emotional dimensions

The pain point distribution in Fig. 3 identifies three critical intervention zones where physical and cognitive strain coincide with emotional deterioration, and these zones became the targeted domains for the subsequent design synthesis.

4.2. Translating Universal Design Principles into Kitchen Design Guidelines

The formulation of the universal design principles into kitchen-specific guidelines entailed reaching the right level of integration between the wide scope of the universal design principles on one hand, and the details of how they were to be translated within the context of kitchen products on the other hand. The definition of each one of the seven universal design principles is comprehensive enough so that they can be applied across all contexts; however, the application of the kitchen product design requires the transformation of each individual principle into sub-principles. This translation was guided by the user studies mentioned above and validated through three separate reviews carried out by experts from design, ergonomics, and gerontology fields respectively.

The translation in Table 1 is not confined to a mere renaming of the principles. Firstly, the principle of equitable use was translated to encompass sub-principles that prohibited the use of any markings or symbols indicating a senior-specific purpose of the product on the basis of user testing, which revealed that the older test users would intentionally avoid using those products that had senior-specific markings on them. The principle of tolerance for error was modified to incorporate not only measures to prevent error by features like automatic shutoff but also mechanisms for error recovery by features like the possibility of resuming the action after an interruption by pressing the button once. It has been found that older test subjects

would sometimes face a frozen state due to an interruption while performing the action and needed a path leading back to their original task instead of restarting from the beginning. The principle of low physical effort received considerable emphasis because of problems with grip and reach experienced during user testing.

Table 1. Translation of the seven principles of universal design into kitchen-specific design guidelines.

Universal Design Principle	Kitchen-Specific Sub-Guidelines	Representative Design Implementation
1. Equitable Use	Product form must avoid visible age-specific coding; aesthetic language must remain consistent with mainstream kitchen products	No color schemes, labels, or graphics that signal senior-oriented framing
	Functional performance must be comparable across user age groups without separation	Shared operation logic usable by all household members
2. Flexibility in Use	Support at least two modes of operation to accommodate different user capabilities	Dual-mode controls combining physical buttons and voice activation
	Allow for both left-handed and right-handed operation	Symmetrical handle design and mirror-accessible control panel
	Permit user-defined interface configurations	Customizable preset buttons for frequent tasks
3. Simple and Intuitive Use	Operation sequence must be reducible to no more than three steps for primary tasks	One-touch cooking start for common programs
	Visual-textual information hierarchy must align with familiar cultural conventions	Standard left-to-right reading order for control displays
4. Perceptible Information	Provide redundant information through at least two sensory channels	Visual indicator plus auditory confirmation tone
	Ensure text and icon legibility under degraded visual conditions	Minimum 14-point font size and high-contrast color pairs
	Feedback response time must remain below perceptible delay threshold	Visual feedback within 500 ms of user input
5. Tolerance for Error	Include passive safety mechanisms that prevent common error consequences	Automatic shutoff after inactivity period and overheat protection
	Provide clear and low-effort error recovery paths	One-touch restart after interruption without requiring full reset
6. Low Physical Effort	Activation force for primary controls must not exceed lower-bound older adult capability	Button activation force below 10 N; knob torque below 0.3 N·m
	Handle and grip dimensions must accommodate reduced hand strength and dexterity	Handle diameter between 35 and 45 mm with textured surface
	Eliminate tasks requiring sustained overhead reaching or deep bending	Pull-down upper storage and lift-up lower drawers
7. Size and Space for Approach and Use	Operational reach zone must remain within comfortable anthropometric range	Primary controls positioned between 850 and 1100 mm height
	Provide clearance for users with mobility aids or seated operation	Minimum 750 mm clear space in front of primary work zones

4.3. Proposed Framework: Inclusive Kitchen Product Design Framework (IKPDF)

The principles of translation presented in Table 1 constitute an important but partial first step towards the implementation of inclusive design with respect to kitchen products. Implementation development in the process requires a structure that will enable designers to (a) classify the principles according to the applicability of each one to the product experience dimension and (b) comprehend the relationship between the dimensions while using the product. This is precisely the reason why IKPDF was developed to address such needs through arranging the sub-principles in a three-layer structure with respect to the three product experience dimensions. Figure 4 demonstrates how each of the seven principles relates not only to one layer but several others as well.

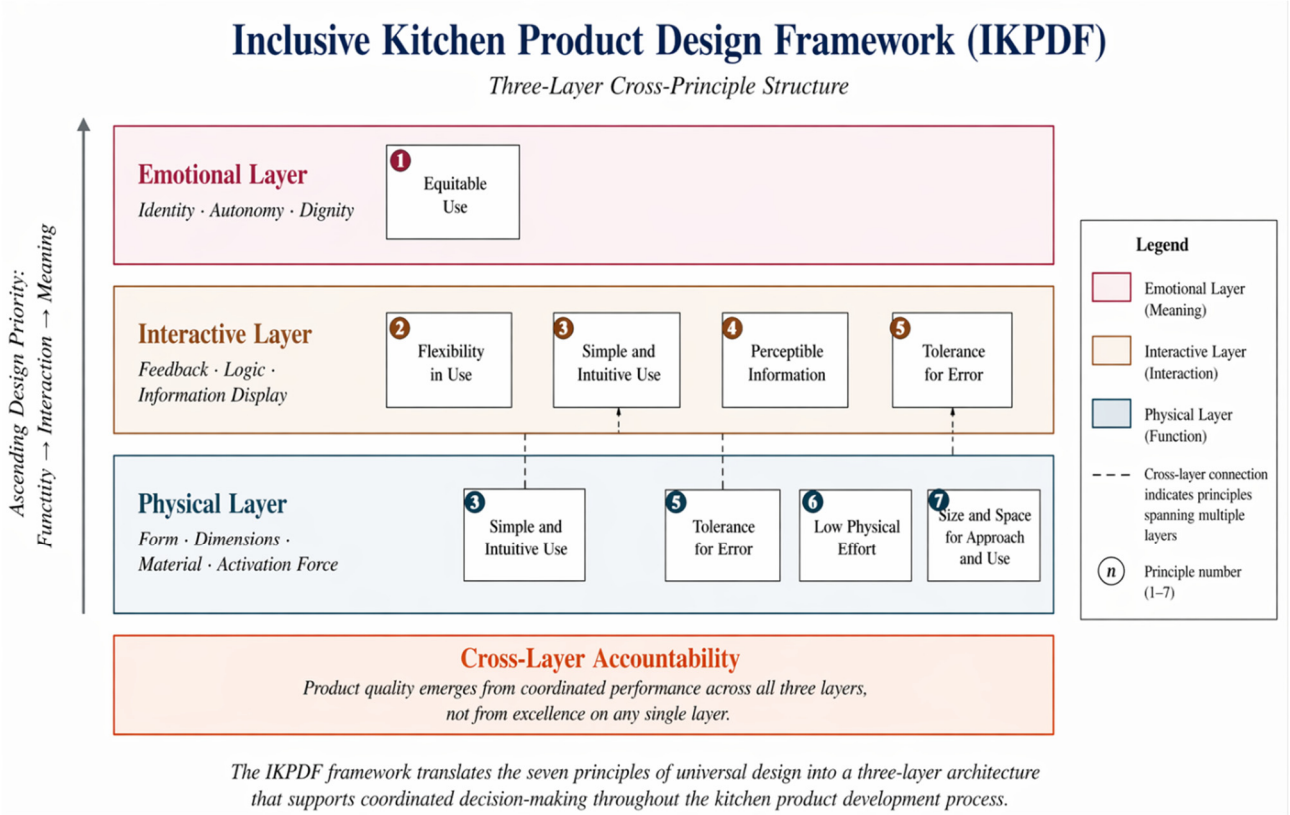


Fig 4. The Inclusive Kitchen Product Design Framework (IKPDF) showing the three-layer structure and the cross-layer distribution of the seven universal design principles.

From Figure 4, it is clear that the physical layer consists of the physical attributes of the product, including shape, size, materials, and activating force. The interactive layer consists of the interactive attributes of the product, including feedback, sequence logic, and information. Emotional layer refers to the positioning of the product with respect to the identity, freedom, and dignity of the user. The attribute of low physical effort pertains to the physical layer alone, while the attribute of ease of use applies to both the physical and interactive layers. Equal opportunity pertains to the emotional layer in that it defines whether the age-based positioning of the product is appropriate.

It is important to point out that the three-layer approach is not only used in a descriptive manner, but serves as an instrument of decision-making in terms of designing products. Designers are expected to provide the guarantee that the process of optimization involves all layers at once. If a product works fine on physical and interactive levels, yet something fails on

the emotional level, like a brand appealing to the old generation visually but failing emotionally because of other reasons, it is likely to be rejected in an assessment process.

4.4. Design Practice: Case Studies of Three Inclusive Kitchen Products

The validity of the IKPDF theory was evaluated using the development of three product designs, whose development was informed by one of the categories chosen from the research framework. These products include an inclusion induction stove that has improved feedback mechanisms. This product improves the physical aspect by having low activation force while improving the interactive aspects by introducing multimodal feedback which includes audio, visual, and even slight haptic feedback. Secondly, the product includes the assisted lifting storage system that has manually adjustable upper cabinets as well as soft closing drawers. This product has improved the physical aspect by making sure there are no instances of overhead reaching activities while improving the emotional layer by using design features that reflect traditional kitchen designs. Finally, there is the multi-handle electric kettle that increases the handle size as well as three buttons. This improves the physical aspect by hand adaptability while improving the interactive aspect by offering immediate error handling upon unintentional button press.

Each product concept was assessed through expert reviews and consultations with senior citizens. The scores for each principle were computed using a five-point scale, and the mean score was obtained using the formula presented in Chapter 1. This data is illustrated in Table 2 along with the mean inclusive design score.

Table 2. Evaluation results of the three product concepts across the seven universal design principles and composite inclusive design scores.

Universal Design Principle	**Weight** w_i	**Concept A: Induction Cooktop**	**Concept B: Lift-Assisted Storage System**	**Concept C: Multi-Grip Electric Kettle**
1. Equitable Use	0.14	4.2	4.5	3.8
2. Flexibility in Use	0.12	3.5	4.0	3.2
3. Simple and Intuitive Use	0.15	3.8	3.6	4.3
4. Perceptible Information	0.15	4.5	4.1	3.9
5. Tolerance for Error	0.18	4.4	4.2	3.7
6. Low Physical Effort	0.16	3.6	4.6	3.5
7. Size and Space for Approach and Use	0.10	3.2	4.0	3.4
Weighted Principal Score $\sum w_i s_i$	—	**3.95**	**4.19**	**3.72**
Interaction Adjustment $\lambda \sum_{i<j} \alpha_{ij}\, s_i s_j$	—	−0.08	−0.07	−0.07
Composite Inclusive Design Score S	—	**3.87**	**4.12**	**3.65**

Based on the data provided in Table 2 above, it is evident that each of the three concepts performs differently from each other. In terms of score, the induction cooktop has a score of 3.87 because it scored high when it came to error tolerance and perceivable information while having a low score in size and space because it is considered a non-extensible concept. The assisted storage system got the highest score among the three concepts, which is 4.12 because it showed a good performance in both physical and emotional dimensions even though it had low scores in terms of simplicity and intuitiveness owing to the fact that operating the lift system requires some learning.

This variance in scores is revealing of something in itself. For none of the elements was there a perfect score with regard to all the seven principles. This demonstrates the correctness of the theoretical statement underlying the scoring mechanism - that is, that there is interrelation between the principles, and they should all be considered holistically and not independently optimized. The fact that there was such a high score achieved by the storage system actually demonstrates coordination within the system rather than excellence with regard to any single principle.

5. Discussion

5.1. Aging, Dignity, and Cultural Equality: A Design-Cultural Perspective

In light of these findings, it is evident that older people do not meekly submit to the products that are seen as being for seniors. In turn, this finding necessitates additional considerations regarding principles upon which an inclusive design framework operates as a concept. The results obtained within this research project confirm earlier findings in relation to the same area, obtained in the course of inclusion of older people into design. Based on these results, it can be argued that if designers take into account not only functionality but also the dignity of users during the development stage of the product, the created items will enjoy higher levels of acceptance, as their design will not have those elements associated with traditional senior products [3].

The cross-generational issue discovered through this study, where the younger generation takes over those duties that are too tough for their older relatives to perform, highlights yet another cultural issue which current user-centric research methodology struggles to address. Research into future trends in kitchens of China by the means of co-design with its younger consumers has revealed that younger generations exhibit their unique requirements regarding the collective usage, eco-friendliness, and interaction with kitchen products [10]. Given the background of such requirements formulated by the younger consumers, the needs of the older people discovered by this research create a unique design dilemma that is only possible in a cultural context of China. The design for the younger users could accelerate the trend of marginalization of the older generation, whereas the product design for the older users alone would fail to attract the younger cooks who frequently influence the purchasing decision making process. To solve this dilemma, more than engineering knowledge is required; the designers must take a design-culture approach to their work based on the principle that the kitchen is intergenerational and not individual. The emotional level of IKPDF addresses this need.

5.2. From Age-Specific to Universal: Rethinking Design Methodology

The choice of treating the seven principles as design principles rather than an evaluation criterion in this study can benefit from insights into some contemporary studies on the acceptance of smart kitchen devices by elderly consumers. Structural equation modeling shows that ergonomics, visual design, functionality, interactive interface design, and brand image are important design considerations in the design of products accepted by the elderly

population, mediated by their perceptions of usability and ease of use, influencing their intentions [8]. Each of these five criteria is associated with the design principles employed in this study, and there appears to be an overlapping point between the two design methodologies. While the five-factor model takes a product design perspective towards user acceptance, the seven design principles are the guiding design principles for achieving user acceptance from the aspect of human capability and dignity.

A second discourse related to the methodology can be found in the analysis of aging-friendly kitchens based on space-based approach. The space syntax methodology provides empirical evidence that certain spatial factors influence the efficiency of older adults in terms of work performance in the kitchen environment, particularly with regard to flows of movement and access to preparation and storage spaces [20]. Although the present study does not deal with spaces, these two methodologies meet each other when it comes to positioning products within spaces. In the IKPDF model, the product layer not only considers the dimensions of the products themselves but also the activation forces acting upon them; however, the successful operation of products in reality also needs a spatial context provided by space syntax methodology.

5.3. Evaluation Results and Theoretical Implications

The wide differentiation of the scores for the three product concepts indicates that there is a benefit in achieving combined performances at all levels rather than achieving a high score in any one level. There are significant theoretical contributions from this result which are independent of the analysis of the specific products. Other research conducted with respect to designing age-friendly kitchens using the AHP and TOPSIS methods reveals that there is more benefit to using a weighted approach in the multi-criteria evaluation of elderly-friendly kitchen design solutions [5]. The proposed composite scoring method in this paper is a modification of the multi-criteria decision-making method through incorporating not just the weighted score of the principle but also the interaction factor.

The validity of the above-mentioned assumption is supported by other studies conducted by means of multimodal assessment using physiological and behavioral approaches to analyze such things as eye tracking, electromyography, pressure testing, and behavioral coding related to the usage of kitchen devices by older people [6]. The results obtained through the use of multimodal assessments have demonstrated that, in some cases, subjective assessments made by the users are inconsistent with physiological responses indicating signs of fatigue and attention difficulties. For example, some participants give their positive evaluations while experiencing muscular and visual attention challenges. The mentioned inconsistency poses an additional question regarding the current study. It is likely that the rating generated from experts' and users' assessments in the validation phase of the IKPDF will not take into consideration the physical strain imposed on the user. Additionally, there was another study in which researchers have found that the visual attention patterns associated with kitchen furniture are mainly concentrated around the focal points corresponding to affordances and information hierarchy [12]. Given the stability of visual attention patterns, the development of the IKPDF should also consider the problem of visual concentration within the interactive level.

5.4. Limitations and Future Research Directions

The above outlined limitations in the current study provide multiple directions for future investigation that could help expand the scope of the theoretical framework. Regarding user research, it should be pointed out that the present analysis is limited to the urban Chinese population. Thus, the idea of applying the IKPDF framework in the context of rural China, East Asian cultures other than Chinese, and Western countries where people grow old should be further explored. It should also be emphasized that in the current study the performance of

the IKPDF framework has been evaluated only during the design concept stage and any future studies on the efficiency of this framework in a long-run application by older adults should be conducted. However, at the moment, it seems to be particularly appealing to explore the direction in which the IKPDF framework might be applied to the development of smart homes that allow for more convenient interactions between people and their environment. Indeed, there have been studies exploring the factors associated with adoption intention of older people towards smart home technology [18]. Thus, incorporating some of the above factors into the future versions of the IKPDF framework could lead to shifting the focus from inclusivity concept evaluation to adoption modeling.

6. Conclusion

From the comparative analysis introduced in the previous section, this paper endeavors to conduct a study on translating the seven principles of UD into inclusive designs for kitchen products suitable for older adults. This paper utilizes both qualitative and quantitative approaches, which follow the four-step research framework of user research, analysis synthesis, design practice, and evaluation. The first two steps outline a series of interconnected physical, cognitive, and emotional concerns related to older adults' experiences in their interactions with kitchen objects. The intergenerational observations within the context of Chinese families have found a hidden distribution of tasks that increasingly denies older adults their independence in the kitchen. Based on this, the paper introduces the Inclusive Kitchen Product Design Framework where the seven principles are arranged according to the physical, interactive, and emotional layers in their product interaction experience. Through the validation tests conducted on three product prototypes, inclusive design ratings of 3.87, 4.12, and 3.65 were achieved for induction cooktop, assisted lifting storage system, and multi-grip electric kettle, respectively. The different performances of these three products indicate that the seven principles work in synergy, not in addition, and coherent performance across all three layers outweighs individual excellence.

The main contribution of this research lies in the connection between universal design theory and its practical implementation for creating cooking appliances that will suit the aged society. In this regard, there is offered both theoretical framework and operation guidelines that will prove beneficial not only for designers, producers and researchers but also can be helpful for the other sciences working on the issue of inclusive design. The importance of this research lies not only in the field of designing cooking appliances but also brings up one of the crucial issues regarding how to address the needs of older population without making them feel discriminated because of their age by means of age-specific products. The transformation of universal design principles into design process is the methodology used in the current research, which can be implemented to develop design in another area similarly. The current research being carried out in China provides an opportunity for the research to start from this very context and then broaden it to some other cultural and technological backgrounds.

References

[1] P. J. Clarkson and R. Coleman, "History of inclusive design in the UK," Applied Ergonomics, vol. 46, Part B, pp. 235-247, Jan. 2015, doi: 10.1016/j.apergo.2013.03.002.

[2] M. Zallio and P. J. Clarkson, "Inclusion, diversity, equity and accessibility in the built environment: A study of architectural design practice," Building and Environment, vol. 206, p. 108352, Dec. 2021, doi: 10.1016/j.buildenv.2021.108352.

[3] J. Lee and J. Park, "Inclusive design process for user-centered wearable products: A case study on lumbar support for older women with chronic low back pain," Clothing and Textiles Research Journal, vol. 43, no. 4, pp. 322-338, 2025, doi: 10.1177/0887302X251339780.

[4] A. Heylighen, V. Van der Linden, and I. Van Steenwinkel, "Ten questions concerning inclusive design of the built environment," Building and Environment, vol. 114, pp. 507-517, Mar. 2017, doi: 10.1016/j.buildenv.2016.12.008.

[5] Y. Xue and Q. Zeng, "Research on age-friendly smart kitchen design based on user behavior and cognition," in Proc. Int. Conf. Human-Computer Interaction (HCII 2025), Q. Gao and J. Zhou, Eds. Cham, Switzerland: Springer Nature, 2025, pp. 152-169, doi: 10.1007/978-3-031-92710-2_10.

[6] C. Xue, M. Liu, Y. Zhai, J. Du, and X. Fu, "Physiological and behavioral analysis based multimodal evaluation of older adults' experience with kitchen appliances," in Proc. Int. Conf. Human-Computer Interaction (HCII 2025), Q. Gao and J. Zhou, Eds. Cham, Switzerland: Springer Nature, 2025, pp. 170-185, doi: 10.1007/978-3-031-92710-2_11.

[7] Z. Xu, Y. Bao, H. Dong, Y. Wu, and G. Tang, "Heart of the future home: A multidimensional model of inclusive kitchen for older people in the UK," Humanities and Social Sciences Communications, vol. 11, no. 1, pp. 1-16, 2024, doi: 10.1057/s41599-024-03508-1.

[8] Y. Li, C. Jiang, S. H. Abdul-Rashid, R. A. R. Ghazilla, and J. Jin, "A structural equation modeling approach to investigating the influence of smart kitchen appliance design features on older adults' technology acceptance," Archives of Gerontology and Geriatrics, vol. 131, p. 105781, 2025, doi: 10.1016/j.archger.2025.105781.

[9] J. Kaczor, B. Fabisiak, M. Bartuzel, P. Domański, O. Marciniak, and T. Wiktorski, "Universal design in kitchen furniture: A case study on enhancing accessibility and safety for the elderly and people with mobility challenges," Annals of Warsaw University of Life Sciences - SGGW, Forestry and Wood Technology, no. 123, pp. 89-102, 2023.

[10] Z. Xu, Y. Wu, Y. Bao, J. Li, and Z. Zhou, "Using co-design to explore new trends in future kitchen designs: An exploratory workshop study of college students in China," International Journal of Environmental Research and Public Health, vol. 20, no. 2, p. 1550, 2023, doi: 10. 3390/ ijerph 20021550.

[11] C. Zhou, W. Zhan, T. Huang, H. Zhao, and J. Kaner, "An empirical study on the collaborative usability of age-appropriate smart home interface design," Frontiers in Psychology, vol. 14, p. 1097834, 2023, doi: 10.3389/fpsyg.2023.1097834.

[12] O. Göktaş, E. Ergin, G. Çetin, H. H. Özkoç, A. Fırat, and G. G. Gazel, "Investigation of user-product interaction by determining the focal points of visual interest in different types of kitchen furniture: An eye-tracking study," Displays, vol. 83, p. 102745, 2024, doi: 10.1016/j.displa.2024.102745.

[13] A. Stamate, M. D. Marzan, M. Velciu, C. Paul, and L. Spiru, "Advancing user-centric design and technology adoption for aging populations: A multifaceted approach," Frontiers in Public Health, vol. 12, p. 1469815, 2024, doi: 10.3389/fpubh.2024.1469815.

[14] L. D. Morris, A. McKay, and T. Cassidy, "A design evaluation tool for older adults using domestic information processing appliances," Applied Ergonomics, vol. 114, p. 104106, 2024, doi: 10.1016/j.apergo.2023.104106.

[15] I. Shafei, J. Khadka, and M. Balasubramanian, "Smart homes: Pioneering age-friendly environments in China for enhanced health and quality of life," Frontiers in Public Health, vol. 12, p. 1346963, 2024, doi: 10.3389/fpubh.2024.1346963.

[16] A. Ghorayeb, R. Comber, and R. Gooberman-Hill, "Development of a smart home interface with older adults: Multi-method co-design study," JMIR Aging, vol. 6, no. 1, p. e44439, 2023, doi: 10.2196/44439.

[17] D. Kim, H. Bian, C. K. Chang, L. Dong, and J. Margrett, "In-home monitoring technology for aging in place: Scoping review," Interactive Journal of Medical Research, vol. 11, no. 2, p. e39005, 2022, doi: 10.2196/39005.

[18] C. Zhou, Y. Qian, and J. Kaner, "A study on smart home use intention of elderly consumers based on technology acceptance models," PLoS ONE, vol. 19, no. 3, p. e0300574, 2024, doi: 10. 1371/ journal. pone.0300574.

[19] H. Chen, N. Anton, R. J. Holden, and D. Yu, "Kitchen ergonomics in health and healthcare: A rapid scoping review," Human Factors in Healthcare, vol. 5, p. 100069, 2024, doi: 10.1016/ j. hfh. 2024. 100069.

[20] Y. Wang, D. Lin, and Z. Huang, "Research on the aging-friendly kitchen based on space syntax theory," International Journal of Environmental Research and Public Health, vol. 19, no. 9, p. 5393, 2022.

[21] K. Carr, P. L. Weir, D. Azar, and N. R. Azar, "Universal design: A step toward successful aging," Journal of Aging Research, vol. 2013, no. 1, p. 324624, 2013.

[22] A.-J. Shie, E.-M. Xu, Z.-Z. Ye, Q.-F. Meng, and Y. J. Wu, "Sustainable innovative design of elderly-friendly smart medical products: An integrated model," Sustainability, vol. 16, no. 17, p. 7580, 2024.