An Empirical Study on the Design of Age-Friendly Household Health Teapots Based on Universal Design Principles and Analytic Hierarchy Process

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Abstract. With the aging society, the demand for home products from the elderly population has been steadily increasing, making age-friendly design a key direction for modern home product development. This paper, based on the principles of Universal Design (UD) and Analytic Hierarchy Process (AHP), uses the "Good Fortune and Wealth" health teapot as a case study. A research model for age-friendly home health teapot design was constructed by investigating and analyzing the needs of elderly people using the KJ method. Through the quantitative analysis of functional needs, safety requirements, and cultural identity of the elderly, key design indicators were identified, such as burn prevention, integration of cultural elements, and simplified operation steps. The design not only takes into account the convenience and emotional needs of elderly users but also incorporates traditional "Fulu" cultural elements to ensure that the product meets the psychological and physiological characteristics of elderly users. After practical testing and user evaluation, the final design received "good" feedback, indicating that this design effectively improves the quality of life of the elderly population and has strong market application potential.

Keywords: Gp Age-friendly design; Universal Design (UD); Analytic Hierarchy Process (AHP); Health teapot design

1 Introduction

With the improvement of living standards, health and wellness have become key topics, especially in China, where wellness culture is deeply rooted. Traditional practices like Chinese medicine and tea-based wellness are integrated into daily life. Modern wellness kettles, as essential household appliances, not only address health needs but also incorporate cultural and emotional elements into their design. This design task, part of the China Vocational Colleges Skills Competition, involves the innovative design of a "“Fu Lu(福禄)”" wellness kettle. It must reflect Chinese culture, pursue aesthetic and innovative shapes, ensure functionality and safety, and include smart elements to meet modern household needs.

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The task combines UD principles to cater to various user groups, especially the elderly. Using the AHP, the functional, emotional, and cultural needs of the elderly will be quantified to propose an innovative solution. The research aims to merge traditional cultural elements with modern design, offering products that provide better care and adaptability for vulnerable groups.

2 Literature Review

2.1 Universal Design Concept

Universal Design (UD) is an approach that considers the diverse needs of users across different ages, abilities, and cultural backgrounds, aiming to make products and environments accessible to all[1]. Its core principles include equitable use, flexibility, simplicity, ease of understanding, tolerance for error, and low physical effort Proposed by architect Ronald Mace, UD has expanded across various fields, including architecture and product design, emphasizing inclusivity. The idea of UD is that needs are not limited to people with disabilities and that many more people will be affected by poor design[2].This concept is especially important for designing products for the elderly, who face mobility, sensory, and cognitive challenges. UD improves their quality of life by creating more inclusive environments. Recent advancements in smart products and wearable tech, such as voice control and automation in smart homes, further extend UD's application for the elderly.

2.2 KJ Method

The Affinity Diagram (KJ Method) was proposed by Professor Kawakita Jiro in 1964 as a method for analyzing and organizing complex problems[3]. By collecting information, synthesizing it, and categorizing it according to their interrelationships, an organized information structure is formed, helping designers clarify complex issues. This method involves collaboration among experts and teams, aggregating demand information into themes in a bottom-up manner, and establishing a structured list of requirements that promotes the integration of collective intelligence. The KJ method can effectively and efficiently integrate the collective wisdom of older users and create a structured pool of needs.

2.3 Hierarchy Process (AHP)

AHP combines qualitative analysis with quantitative analysis. According to the overall goal of the problem, it decomposes the problem into several factors from a systematic point of view and forms a hierarchical structure model according to its dominant relationship.[4]AHP helps designers quantify the importance of different design requirements and prioritize the most critical needs. AHP can provide decision-makers with comprehensive evaluation criteria, weights, and analyses, thereby reducing the risk of decision bias. The application of AHP can offer a clearer, more concrete, and more feasible guidance for product conceptual design decisions[5-7]. Through AHP, designers can determine the weights of aspects such as functionality, comfort, and cultural elements, providing a scientific basis for product design.

3 Design Model Based on the KJ-UD-AHP Method

The decision-making evaluation of design solutions involves two main stages: determining the relative importance of evaluation criteria and ranking solutions. To minimize discrepancies between expert evaluations and elderly expectations, both stages must be considered together[8]. First, the KJ method is used to gather and organize the needs of elderly users, ensuring comprehensive and accurate data. Then, an AHP-based weight evaluation index, combined with UD, is created to assess the design solutions. Through this evaluation and weight calculation, design solutions are optimized. The AHP-derived weight values guide quantitative analysis, helping decision-makers select the solutions best suited to user needs. This approach reduces subjective bias and ensures solutions align with the real needs of elderly users and avoids the pitfalls of subjective and unfounded creative thinking .as shown in Figure 1.

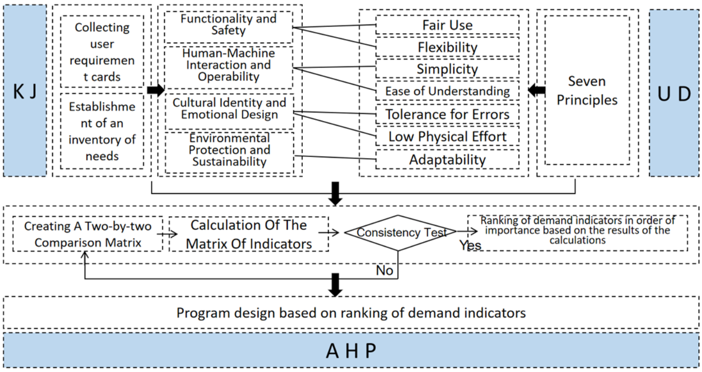

Fig. 1. Product Innovation Design Model Based on KJ-UD-AHP

3.1 Needs Research

The KJ method is a systematic approach that begins by extensively gathering user demand information through various research methods[9].This information is then organized into cards, which are clustered based on their associations to form a clear hierarchical structure of needs, including the naming of the first and second levels. This process not only helps designers effectively sort out the demand criteria but also allows users to more intuitively understand the hierarchical relationships during the subsequent weight allocation. The structured model constructed using the KJ method can be directly applied to the hierarchical structure model of the AHP method, providing a scientific basis for decision-making.

3.2 Establishing the Evaluation Index System and Determining Weights

The Analytic Hierarchy Process (AHP) evaluates decisions made by experts by calculating and aggregating their data[10]. Using the mean method, the optimal aggregated matrix is obtained for evaluation. After consistency testing, the option with the highest weight is selected as the optimal choice. The AHP process is primarily divided into five steps:

Step 1: Constructing the Judgment Matrix

The judgment matrix is established based on expert scores, where scoring is performed using the scale of importance table, as shown in Table 1:

Table 1. Scale of Importance.

Relative Importance of Factor i to Factor j	Quantitative Value
Equally important	1
Slightly more important	3
Moderately more important	5
Strongly more important	7
Extremely more important	9

The judgment matrix is constructed as shown in the formula below:

$$A = \left(a_{ij}\right)_{m*n} = \begin{bmatrix} a_{11} & \cdots & a_{1n} \\ \vdots & \ddots & \vdots \\ a_{m1} & \cdots & a_{mn} \end{bmatrix} \tag{1}$$

Step 2: Calculating Weights of the Judgment Matrix:

$$B_i = \Pi_{j=1}^{n} a_{ij} \tag{2}$$

Calculate the Nth root of B_i:

$$W_i = \sqrt[n]{B_i} \tag{3}$$

Normalize W_i to obtain the weights of the judgment matrix:

$$\overline{W_i} = W_i / \sum W_i \tag{4}$$

Step 3: Calculating the Maximum Eigenvalue of the Judgment Matrix

The maximum eigenvalue is calculated as follows:

$$\lambda_{max} = \frac{1}{n} \sum_{i=1}^{n} \frac{(Aw)_i}{w_i} \tag{5}$$

Step 4: Consistency Index (CI) Calculation

The consistency index is computed as:

$$CI = (\lambda_{max} - n)/(n - 1) \tag{6}$$

The corresponding RI value for a judgment matrix of order n is obtained from Table 2:

Table 2. Random Consistency Index (RI)

Order n	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.52	0.89	1.12	1.26	1.36	1.41	1.46	1.49

Step 5: Consistency Ratio (CR) Calculation
The consistency ratio is computed as follows:

$$\mathrm{CR} = \mathrm{CI}/\mathrm{RI} \tag{7}$$

4 Design Practice of an Elderly-Friendly Household Health Kettle

4.1 Building a Hierarchical Model of Needs Indicators

Using the KJ method, innovative design needs for an elderly-friendly household health kettle were identified through field surveys in Changzhou, Jiangsu, China. Respondents included elderly individuals, family members, and professionals in elderly product design. Interviews provided data that were screened, categorized, and grouped into tertiary-level needs indicators. These were further consolidated into secondary-level (solution level) and primary-level (goal level) indicators.

Following universal design principles, 13 solution-level indicators were classified under four criteria-level indicators: Functionality and Safety, Human-Machine Interaction and Operability, Cultural Identity and Emotional Design, and Environmental Protection and Sustainability. Together, the goal, criteria, and solution levels formed a structured needs framework (see Fig. 2).

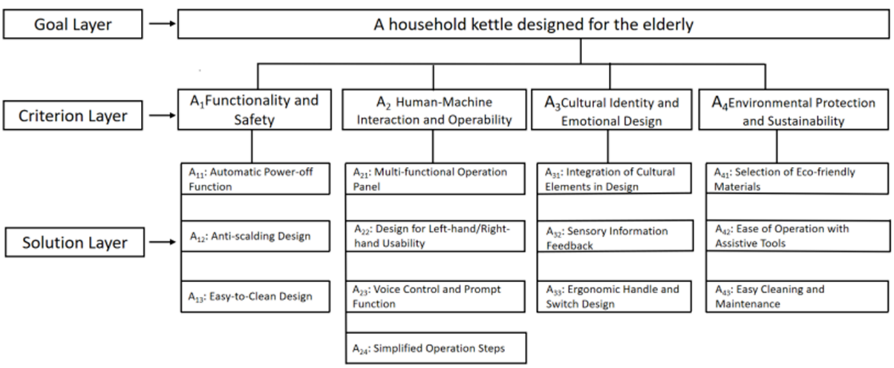

Fig. 2. Hierarchical model of innovation demand indicators

4.2 Weight Determination Based on the Analytic Hierarchy Process (AHP)

To construct the judgment matrix, questionnaires were distributed to 10 experts, all of whom responded. The scores provided by the experts were used to calculate the geometric mean, leading to the results shown in Tables 3–7.

Table 3. Judgment Matrix and Weights for Criterion Layer A

A	A_1	A_2	A_3	A_4	Weight	Consistency Check
A_1	1	1.1467	1.4891	1.2241	0.2978	λmax=4.031
A_2	0.8721	1	0.8899	1.4651	0.2557	CI=0.01032
A_3	0.6715	1.1237	1	1.2509	0.2441	CR=0.0116
A_4	0.8169	0.6825	0.7994	1	0.2024	

Table 4. A1Judgement matrix and weights

A_1	A_{11}	A_{12}	A_{13}	Weight	Consistency Check
A11	1	0.5576	1.4998	0.2926	λmax=3.0016
A12	1.7935	1	2.3874	0.5043	CI=0.00082
A13	0.6668	0.4189	1	0.203	CR=0.0116

Table 5. A2 Judgement Matrix and Weight

A_2	A_{21}	A_{22}	A_{23}	A_{24}	Weight	Consistency Check
A_{21}	1	0.6145	3.053	0.4489	0.2094	λmax=4.0937
A_{22}	1.6273	1	3.4979	0.5432	0.2899	CI=0.03124
A_{23}	0.3276	0.2859	1	0.3356	0.092	CR=0.0351
A_{24}	2.2275	1.8411	2.9798	1	0.4087	

Table 6. A3 Judgement matrix and weights

A_3	A_{31}	A_{32}	A_{33}	Weight	Consistency Check
A_{31}	1	2.519	1.5896	0.4941	λmax=3.0001
A_{32}	0.397	1	0.6504	0.1981	CI=0
A_{33}	0.6291	1.5375	1	0.3077	CR=0

Table 7. A4 Judgement matrix and weights

A_4	A_{41}	A_{42}	A_{43}	Weight	Consistency Check
A_{41}	1	0.8056	1.0251	0.3098	λmax=3.0013
A_{42}	1.2414	1	1.4133	0.3983	CI=0.00063
A_{43}	0.9755	0.7076	1	0.2919	CR=0.0012

4.3 Analysis of Weights for Need Indicator

The AHP results are summarized in Table 8, which shows the weight rankings of criteria and solution layers for the overall goal. Among the criteria layers, Functionality and Safety had the highest weight. Among the 12 solution-layer indicators, the top three factors were Anti-Scald Design (A_{12}, 0.1502), Cultural Element Integration (A_{31}, 0.1206), and Simplified Operation Steps (A_{24}, 0.1045), accounting for a total of 35.3%.

The solution-layer indicators were categorized into three levels based on their importance:Critical Indicators (≥0.09): Anti-Scald Design (A_{12}), Cultural Element Integration (A_{31}), and Simplified Operation Steps (A_{24}).Very Important Indicators (≥0.07): Automatic Power-Off (A_{11}), Ease of Tool-Assisted Operation (A_{42}), and Ergonomic Handle and Switch Design (A_{33}).Moderately Important Indicators (≤0.06): Other design factors.These analyses provide a scientific basis for prioritizing design elements.

Table 8. Results of target weighting

Criterion Level		Scheme Level		Comprehensive Weight	Ranking
Factor	Weight	Factor	Weight		
A_1Functionality and Safety	0.2978	A_{11} Automatic Power-off Function	0.2926	0.0871	4
		A_{12} Anti-Scald Design	0.5043	0.1502	1
		A_{13} Easy-to-Clean Design	0.203	0.0605	9
A_2Human-Machine Interaction and Operability	0.2557	A_{21} Multifunctional Control Panel	0.2094	0.0535	11
		A_{22} Design for Left-Handed/Right-Handed Operation	0.2899	0.0741	7
		A_{23} Voice Control and Prompt Function	0.092	0.0235	13
		A_{24} Simplified Operational Steps	0.4087	0.1045	3
A_3Cultural Identity and Emotional Design	0.2441	A_{31} Integration of Cultural Elements	0.4941	0.1206	2
		A_{32} Sensory Information Feedback	0.1981	0.0484	12
		A_{33} Ergonomic Handle and Switch Design	0.3077	0.0751	6
A_4 Environmental Friendliness and Sustainability	0.2024	A_{41} Selection of Eco-Friendly Materials	0.3098	0.0627	8
		A_{42} Compatibility with Assistive Tools	0.3983	0.0806	5
		A_{43} Ease of Cleaning and Maintenance	0.2919	0.0591	10

4.4 Design Proposal

Based on the AHP evaluation, the design of an elderly-friendly household health kettle prioritizes the top five need factors: Anti-Scald Design (A_{12}), Integration of Cultural Elements (A_{31}), Simplified Operational Steps (A_{24}), Automatic Power-Off Function (A_{11}), and Ease of Tool-Assisted Operation (A_{42}) (Table 8).

Inspired by the gourd, a symbol of happiness, health, and longevity in Chinese culture, the design incorporates this auspicious element. The team refined the concept through hand-drawn sketches and Rhino 3D modeling to ensure feasibility and aesthetic appeal .

The “Fu Lu(福禄)” culture symbolizes happiness, health and longevity in traditional Chinese culture, and these elements are highly compatible with the psychological needs of the elderly. By incorporating the “Fu Lu” elements into the design of a healthy teapot, we not only satisfy the elderly's sense of identity with traditional culture, but also enhance the emotional value of the product. For example, the gourd-shaped handle and red lid not only have aesthetic significance, but also convey good wishes for the user's health and longevity through symbolic design language.

Table 9. Design Programme Concept

Indicator	Functional Dimension Design	Design Proposal Display
A_{12}	The kettle features a double-layer insulation design for a gentle external touch, reducing scalding risk. Its wide, stable shape ensures easy grip and pouring for elderly users, while preventing slippage and usage difficulties.	
A_{31}	The gourd-shaped handle and red lid incorporate traditional "Fu Lu" elements, enhancing cultural identity and symbolizing health, longevity, and well-wishes.	
A_{24}	The kettle has an intelligent temperature control system for one-button adjustment of water temperature and mode, simplifying usage. It also features a clear LED display showing real-time temperature and mode, making it easier for elderly users to track its status.	
A_{11}	The kettle features a color-changing handle tip for temperature indication and a visible water level line. It automatically cuts off power when the water boils or reaches the preset time, preventing accidents from user negligence.	 
A_{42}	The round-bottom recessed design enables 360-degree rotation, making it easy for elderly users to pour. It's lightweight, easy to use, and suitable for people of all ages.	

Through user research, we found that elderly users have a high degree of acceptance of the cultural elements of “Fortune and Prosperity”, especially the gourd-shaped handle and red lid, which are considered to be both beautiful and culturally rich. One interviewee said: “This teapot is not only functional, but also reminds me of the traditional tea set in my childhood home, which feels very familiar.” In the design process, we continuously optimized the expression of cultural elements through multiple prototyping and user testing. For example, in the initial design, the gourd-shaped handle was relatively complicated. After being simplified, it not only retained the recognizability of the cultural symbol, but also improved the ease of use (Table 9).

Evaluation of the Design Proposal：A satisfaction survey was conducted among 56 elderly users (aged 60-70) to assess whether the Elderly-Friendly Household Health Kettle meets development standards. The evaluation criteria included Anti-Scald Design (A_{12}), Cultural Element Integration (A_{31}), Simplified Operation Steps (A_{24}), Automatic Power-Off Function (A_{11}), and Ease of Tool-Assisted Operation (A_{42}), with a grading system from Excellent (90-100) to Fail (below 60). A total of 50 valid surveys were collected, yielding a final score of 85 points (Good). The results confirm that the design generally meets consumer needs and product development requirements, marking the proposal as complete (see Fig. 3).

Fig. 3. Final Solution Showcase

5 Conclusions

This study combines Universal Design (UD) and the Analytic Hierarchy Process (AHP) to explore elderly users' needs in home product design, using the "Fu Lu" health kettle as a case study. By collecting demand information with the KJ method and analyzing it with AHP, the design met elderly users' functional, safety, and cultural needs. Key innovations like anti-scald design, cultural integration, and simplified operation were validated through field research and expert reviews. A satisfaction survey rated the proposal as "Good," indicating its potential to improve elderly users' quality of life. This research provides scientific support for elderly-friendly product design and insights into modernizing traditional cultural elements.

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