AHP-Based Research on Age-Friendly Bathroom Product Design

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Abstract. With China's aging population trend accelerating and the phenomenon of empty-nest seniors intensifying, this study employs the Analytic Hierarchy Process (AHP) to explore design methodologies for age-friendly bathroom products. This approach aims to enhance seniors' quality of life and safety while fully considering their physical and psychological characteristics. First, information on bathroom products for the elderly was gathered through questionnaires and user interviews, followed by attribute classification based on their needs analysis. Second, the AHP hierarchical analysis method was introduced to construct a hierarchical model of elderly needs. A judgment matrix was established, weight coefficients were calculated, and comprehensive rankings were determined.Finally, consistency tests were conducted to validate the rationality of the design scheme. This process derived the priority levels of design elements for age-friendly bathroom products, guiding practical design efforts. The goal is to create age-friendly bathroom products that offer both operational convenience and high safety for the elderly in home settings, while also providing research insights and references for the design of similar age-friendly products.

Keywords: Product Design, Age-Friendly, Bathroom Products, Elderly China's

1 Introduction

It is estimated that China's elderly population will reach approximately 300 million by 2025, surpass 400 million by 2033, and exceed 483 million by 2053. Consequently, the silver economy is rapidly expanding, with demand for age-friendly products steadily increasing—particularly in the design of everyday household items. The bathroom space is an area closely tied to daily life, and research on bathroom products is crucial for enhancing the quality of life for the elderly[1]. However, as seniors experience physical decline and functional deterioration, those aging in place still face challenges in bathroom settings. These include inadequate aging-in-place features, poor safety and protective measures, operational difficulties, and a lack of consideration for emotional experiences, failing to meet the bathroom needs of seniors living at home[2]. In age-friendly design research, the aging process manifests distinct physiological and psychological characteristics at different stages. Therefore, the design

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process must fully integrate emotional needs and humanistic care. The design objective in this field lies in accurately identifying the genuine demands of elderly users, achieving a seamless transition from needs analysis to engineering design, and thereby establishing a systematic, rational, and scientific R&D framework for age-friendly bathroom products. This study systematically collects elderly users' bathroom product usage information through questionnaires and interviews. Employing the Analytic Hierarchy Process (AHP) methodology, it translates user needs into product design elements. By establishing a judgment matrix, calculating weight coefficients, and performing comprehensive ranking, the AHP ultimately validates design rationality through consistency testing. Practical case studies further enhance the age-friendly performance of bathroom products, elevating the elderly's daily bathroom experience to one of comfort and natural usability.

2 Current Situation Analysis

Currently, China is not only a major consumer market for bathroom products globally but also one of the most fiercely competitive regions in this industry. Theoretically, domestic research in this field is relatively abundant, yet design discussions for the elderly population predominantly focus on universal barriers caused by declining physiological functions. This research direction is closely tied to the physiological, psychological, and lifestyle changes that occur as older adults age. While bathroom products continue to evolve, they primarily address basic physiological needs without fulfilling the higher-level emotional and psychological aspirations of the elderly. Furthermore, traditional designs for daily bathroom use by seniors still face numerous challenges requiring improvement in safety, usability, comfort, and accessibility. The Analytic Hierarchy Process (AHP), established in the early 1970s by Professor Ladislaus Saaty of the University of Pittsburgh, is primarily used to address complex decision-making problems involving multiple criteria. Traditional weighting methods often carry significant subjectivity and struggle to systematically integrate qualitative judgments, making AHP a more scientific approach for evaluating user needs. As a weighting analysis method that balances qualitative and quantitative aspects, AHP constructs hierarchical structures based on different objectives. Through layer-by-layer comparisons, it clarifies the relative importance of each factor, making weight judgments more systematic and scientific. Numerous academic studies have applied this method to user needs research. Chen Shanshan, Duan Qijun, Li Yajun et al[3] employed AHP to extract key meaning clusters in designing a pediatric dental service system, thereby advancing its development. Therefore, when designing age-friendly bathroom products, applying the AHP hierarchical analysis method involves first defining the attribute categories of user needs through extensive questionnaires and interviews. Subsequently, AHP is used to analyze the relative weights of different needs, thereby establishing a prioritized sequence of requirements. This provides a clear design direction for age-friendly bathroom products.

3 User Analysis

As people age, their physiological functions generally decline, primarily manifested in reduced muscle strength and an increased prevalence of various diseases. Therefore, when designing bathroom products for the elderly, it is important to consider that individuals over 60 (for women) and 65 (for men) often experience declining hearing and vision, reduced limb flexibility, weakened balance, and mobility challenges. These changes significantly impact their ability to perceive their surroundings and receive information, making it difficult to perform movements requiring greater range or intensity, thereby reducing their independence. Consequently, developing age-friendly bathroom products necessitates incorporating functional assistive design while fully considering accessibility principles to create safer, more comfortable, and easier-to-use bathroom solutions. Additionally, older adults often possess strong self-esteem and are sensitive to external perceptions. They deeply desire respect and understanding from others while also being prone to feelings of inferiority and loneliness due to declining physical functions and shifting social roles. Many seniors still aspire to maintain their independence in daily living, pursuing self-worth and social dignity. This reflects their deep-seated need for self-actualization.

4 Design Research Based on the AHP Analysis Method

4.1 Extraction of Product Design Elements

This study collected target users' perceptions of current bathroom products and their future expectations through questionnaires and in-depth interviews. The gathered user needs were categorized into three design dimensions: functional requirements, user psychology, and aesthetic design. Regarding functional requirements, considering the physiological decline in elderly users' physical capabilities, age-friendly bathroom products must incorporate assistive mechanisms such as support seats. To address potential emergencies during bathroom use by seniors, products should be equipped with safety monitoring and anomaly alert systems. Considering the diminished sensory perception of the elderly, product operation should be simple and intuitive, with clear and unambiguous information displays. Furthermore, given the typically limited space in bathrooms, products should adopt foldable or easily storable designs to minimize spatial occupancy. On the psychological level, age-friendly bathroom products should foster a sense of familiarity and comfort to alleviate the alienation and anxiety the elderly may experience when encountering new equipment. Products must convey an impression of safety and reliability. Simultaneously, designs must respect and uphold seniors' dignity and privacy needs. Functional and structural planning should balance practicality and cost-effectiveness, avoiding excessive pursuit of smart features to ensure core functionality within manageable budgets. Aesthetically, products should feature clean, gentle lines with harmonious, bright color schemes that blend seamlessly into home environments. Material selection should prioritize durability, safety, light-

weight properties, and eco-friendliness, avoiding heavy or difficult-to-clean materials to ensure usage safety and optimize user experience.

4.2 Constructing Hierarchical Models

Using the Analytic Hierarchy Process (AHP), the design elements for age-friendly bathroom products collected and extracted in the preliminary phase are transformed into a hierarchical model:(1) The objective layer is defined as "Age-Friendly Bathroom Product Design," denoted as A.(2) The criterion layers are defined as "Functional Requirements," "Psychological Needs," and "Appearance Design," denoted as B1, B2, and B3 respectively.(3) Establish the indicator layer as "height adjustment," "assistive seating," "user-friendly operation," "safety monitoring," "information visualization," "foldable storage," "anti-collision and anti-slip," "easy cleaning," "sense of security," "privacy," "cost-effectiveness," "clean and harmonious color scheme," and "simple and gentle styling," denoted as C1-C13 respectively, as shown in Figure 1.

4.3 Evaluation Indicator Construction: Judgment Matrix and Weight Calculation

To calculate the relative importance of each indicator within a given level compared to the preceding level, pairwise comparisons were primarily employed to derive the weight values for indicators within each level, thereby constructing a scientifically sound judgment matrix[4]. Three experts were invited to participate in a group discussion, where they conducted pairwise comparisons of indicators within the same level using Sarti's 1–9 scale method[5], as shown in Table 1. Scores were assigned to each indicator, yielding the judgment matrices for both the criteria layer and the indicator layer of the age-friendly bathroom product standards. Weight calculations and consistency tests were performed on the matrices. The criteria layer judgment matrix and its results are shown in Table 2, while the indicator layer judgment matrices and their results are presented in Tables 3–5.

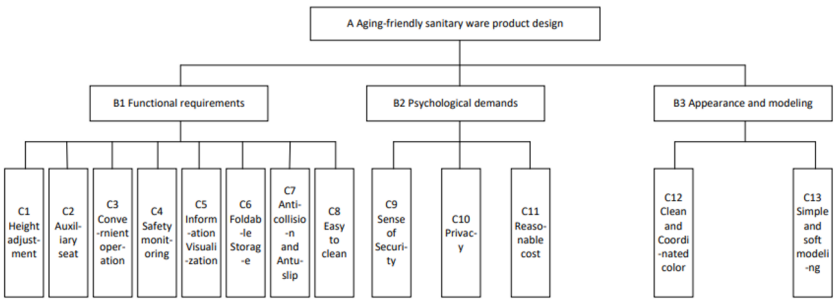

Fig. 1. Hierarchical Analysis Model

Table 1. 1 to 9 scale

Scale	Meaning
1	Indicator X is as important as Indicator Y
3	Indicator X is slightly more important than Indicator Y
5	Indicator X and Indicator Y are clearly important
7	Indicator X and Indicator Y are highly important
9	Indicator X and Indicator Y are extremely important
2, 4, 6, 8	Intermediate value between two adjacent judgments
Reciprocal	Comparing two indicators in reverse gives the reciprocal of the original ratio

Table 2. Criteria Layer Judgment Matrix and Weights

Criterion layer	B1	B2	B3	Weight value	Consistency ratio	λmax
B1	1	4	6	0.6853		
B2	1/4	1	3	0.2213	0.079	3.092
B3	1/6	1/3	1	0.0934		

Table 3. "Functional requirements"Judgment matrix and weights of various indicators

B1	C1	C2	C3	C4	C5	C6	C7	C8	Weight value	Consistency ratio	λmax
C1	1	3	1/2	1/5	2	1	1/4	2	0.0819		
C2	1/3	1	1/4	1/7	1/2	1/3	1/6	1/2	0.0322		
C3	2	4	1	1/3	3	2	1/2	3	0.1395		
C4	5	7	3	1	6	4	1	5	0.3048	0.016	8.157
C5	1/2	2	1/3	1/6	1	1/2	1/5	1	0.0496		
C6	1	3	1/2	1/4	2	1	1/3	2	0.0867		
C7	4	6	2	1	5	3	1	4	0.2528		
C8	1/2	2	1/3	1/5	1	1/2	1/4	1	0.0525		

4.4 Comprehensive Ranking

In order to prevent the appearance of the inffuence of subjective factors of the scorer, the data were tested for consistency. First, the consistency indicator CI was calculated:where max is the maximum eigenvalue of the judgement matrix and n is the order of the judgement matrix. Finally, the consistency ratio coefffcient CR is calculated:RI is the average random consistency index, RI is shown in Table.

$$CI = \frac{\lambda_{max} - n}{n-1} \tag{1}$$

$$CR = \frac{CI}{RI} \tag{2}$$

The obtained weight data undergoes comprehensive processing. Specifically, the weight coefficients of user needs are multiplied by the evaluation values of corresponding scheme elements to derive a quantitative ranking reflecting the overall importance of each alternative. This ranking serves as a reference for decision-making in age-friendly bathroom product design. Detailed data is shown in Table 6.

Table 4. Judgment Matrix and Weights of Various Indicators for "Psychological Needs"

B2	C9	C10	C11	Weight value	Consistency ratio	λmax
C9	1	5	3	0.6334		
C10	1/5	1	1/3	0.1061	0.0328	3.038
C11	1/3	3	1	0.2605		

Table 5. Criteria Evaluation and Weighting for "Appearance & Styling"

B3	C12	C13	Weight value	Consistency ratio	λmax
C12	1	1/3	0.250	0.000	2.000
C13	3	1	0.750		

Table 6. Sorting of indicator weights

Indicator Layer	Weight	Sorting
C1 Height adjustment	0.0561	8
C2 Auxiliary seat	0.0220	13
C3 Convenient operation	0.0956	4
C4 Safety monitoring	0.2089	1
C5 Information visualization	0.0340	10
C6 Foldable storage	0.0594	6
C7 anti-collision and anti-slip	0.1732	2
C8 Easy to clean	0.0360	9
C9 Sense of security	0.1402	3
C10 Privacy	0.0235	11
C11 Reasonable cost	0.0573	7
C12 Clean and coordinated color	0.0233	12
C13 Simple and soft modeling	0.071	5

5 Design Practices for Age-Friendly Bathroom Products

5.1 Design Strategies

Based on research into the Analytic Hierarchy Process (AHP) for age-friendly bathroom products, the designed product solution primarily involves extracting design elements through the ranking of quantified relative weights for quality factors. This

process integrates human-computer interaction data relevant to the elderly and analysis of bathing behavior. By reviewing relevant literature and data, appropriate physical dimension parameters and percentiles for the elderly were selected and analyzed to determine optimal product dimensions for senior-friendly bathrooms, as shown in Table 7. The final age-friendly bathroom product solution is presented in Figure 2. (1) At the functional design level, the product features foldable handrails and seating for elderly users during showering, providing stable support to reduce fall risks caused by physical weakness or instability. Its foldable design also helps conserve limited bathroom space. Built-in health monitoring sensors collect real-time vital signs such as heart rate and body temperature during bathing, displaying the data on a centralized screen. This screen also provides alerts for water temperature and bathing duration. Additionally, the product integrates a one-touch emergency call button and fall detection sensors, supporting both manual and automatic abnormal status alerts to promptly notify other household members. (2) Material Selection The main body utilizes polycarbonate plastic and stainless steel, both offering excellent mechanical strength and chemical corrosion resistance. This ensures structural durability and longevity, with smooth surfaces that facilitate easy cleaning. Areas in direct contact with the body, such as handrails and seats, are covered with polyvinyl chloride (PVC) plastic to enhance slip resistance. All three materials selected are non-toxic, odorless, and low-density, balancing lightweight construction with environmental friendliness. (3) In structural design, the main load-bearing frame utilizes easily machinable stainless steel tubing to ensure overall stability. By streamlining smart interactive functions and integrating them into a dedicated control module, manufacturing costs and maintenance complexity are reduced while operational simplicity is enhanced, improving both practicality and serviceability. All structural edges feature smooth, gentle curves to prevent secondary injuries from falls during elderly bathroom use.

5.2 Design Proposal Verification

To evaluate the product's practical application effectiveness, the research team organized a targeted user test. Participants provided quantitative feedback on the product's subjective evaluation based on their personal experience and family member scoring methods, covering aspects such as usage effectiveness, physical comfort, and overall satisfaction. Quantitative assessment was conducted using a structured 5-point Likert scale (1-5 corresponding to “Very Dissatisfied” to “Very Satisfied”), with mean scores calculated for each metric to reflect overall user satisfaction. Average scores for each evaluation indicator are shown in Figure 3. The overall satisfaction mean of 4.25 indicates fundamental approval of the final design solution among the target user group and validates its feasibility.

Table 7. Optimal Dimension Reference Table for Age-Friendly Bathroom Products

Scale Name	Range of values/mm	Optimal value/mm
Height of the bathing chair	400~500	450
Width of the bathing chair	320~800	320

Height of the handrail from the ground	≥700	800
Armrest thickness	30~40	30
Showerhead height	≥1850	1900
Height of shower equipment switch	589~977	700
Distance from the wall head to the side wall	≥404	450

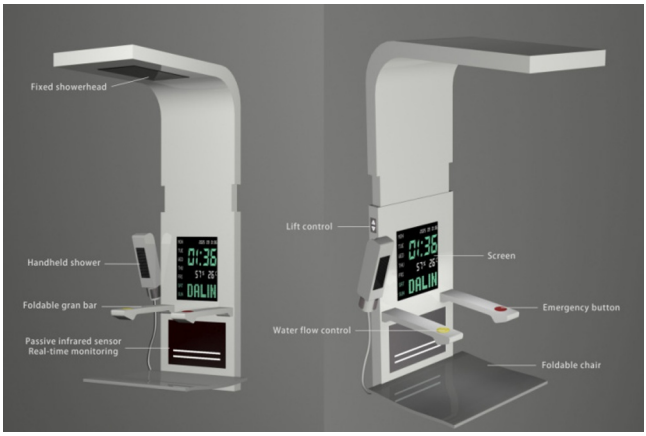

Fig. 2. Product Design Rendering

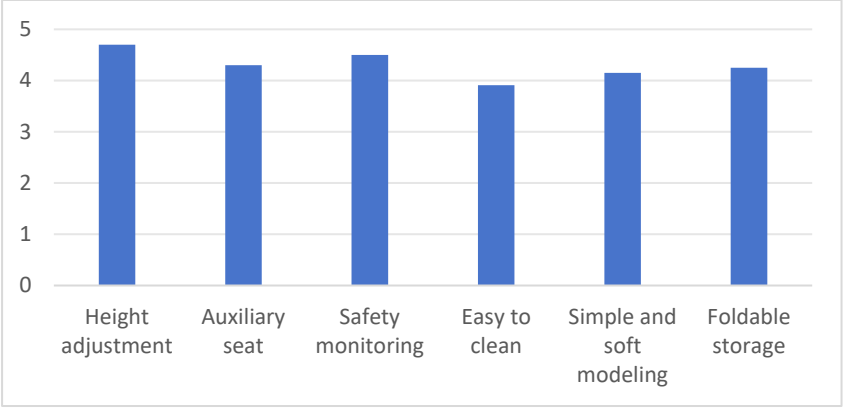

Fig. 3. Design Evaluation Results

6 Conclusion

The aging trend in contemporary society continues to intensify, yet many everyday products still fail to adequately meet the practical needs of elderly users. Age-friendly design can alleviate the challenges faced by this demographic, infusing greater convenience and humanistic care into their daily lives. Based on extensive research, this study identifies specific demand indicators exhibited by seniors during bathing activi-

ties. Utilizing the Analytic Hierarchy Process (AHP) for weight calculation, it achieves a synthesis of subjective and objective perspectives. By translating the importance of each requirement into intuitively presentable data, a scientifically sound evaluation system for age-friendly bathroom products is established to guide design practice. The age-friendly bathroom design solutions developed through the AHP method significantly enhance the bathing experience for elderly users while providing practical pathways and case references for innovative product design in this category.

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