

Modular Table-Chair-Storage Nesting Sets Design for Home-Based Elderly Care in Compact Apartments: An Integrated Evaluation Approach

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As the average age of people continues to increase in many countries, compact urban apartments present significant challenges to the functional adaptability of living environments. This creates new difficulties with the design of elderly-friendly furniture. This study explores the modularization and configuration of furniture in limited spaces to satisfy the requirements of aging-in-place, particularly regarding comfort, convenience, and safety. First, the Affinity Diagram (AD) method was employed to systematically categorize user needs and construct an evaluation system. Second, an integrated weighting method combining Order Relation Analysis (ORA) and the Coefficient of Variation (CV) was applied to obtain a comprehensive weighted ranking of these needs, guiding the development of three design schemes for Modular Table-Chair-Storage Nesting Sets. Finally, the VlseKriterijumska Optimizacija I Kompromisno Resenje (VIKOR) method was used to select the optimal scheme. Subsequently, verification was conducted through simulation experiments. This study proposes a systematic framework to meet user needs, providing reliable support for modular table-chair-storage nesting sets design in space-constrained elderly care scenarios, thereby improving both space utilization and product safety.

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INTRODUCTION

According to the United Nations' "World Population Prospects" report (2024), it is projected that by the end of the 2070s, the global population aged 65 and over will reach 2.2 billion, exceeding the number of children under 18. By the mid-2030s, the population aged 80 and over is expected to reach 265 million. In this context, "Home-based elderly care" is gradually becoming a new form of elderly care. In the scenario of home-based elderly care, the living spaces of most elderly people are compact urban apartments, with the floor area of such apartments typically not exceeding 60 square meters. The apartment layout consists of a separate bedroom and a combined dining and living area, which caters to the daily life, social interaction and basic activity needs of the elderly. However, due to the objective limitations of the compact space, traditional furniture designs are unable to fully meet the core demands of the elderly for living safety, comfort in use and multi-functional space. For example, Jin *et al.* (2025) observed that the surface roughness, gloss, and color characteristics of furniture materials significantly influence the emotional experience of the elderly. Similarly, Zhou *et al.* (2022) utilized motion capture technology

to reveal key changes in human body angles during the process of rising from a sofa, emphasizing the critical value of comfort and smart features in design. Nevertheless, current age-friendly furniture design is still constrained by issues such as a misalignment between design features and user needs, prominent functional limitations, and inadequate safety considerations. Therefore, exploring modular table-chair-storage nesting sets design approaches that balance functionality, comfort, and safety in the context of compact living environments for the elderly is of significant practical importance and research value.

This study responds to the furniture design challenges of home-based elderly care by proposing a complete modular design and evaluation framework. The primary research objectives include: (i) identifying the elderly's core functional and ergonomic requirements for using furniture in compact living environments through user surveys and demand classification, so as to provide a reliable basis for design decision-making; (ii) developing reasonable modular table-chair-storage nesting set configurations *via* functional decomposition to meet diverse spatial and practical needs; and (iii) evaluating and screening alternative design schemes through multi-criteria decision-making methods, and further verifying the overall rationality of the optimal design via ergonomic simulation and validated through ergonomic simulation.

To achieve the above research objectives, this study adopts a hybrid qualitative and quantitative research methodology. First, user needs were collected and classified using the Affinity Diagram (AD) method to establish a furniture design evaluation system. Second, eight experts were invited to determine the weights of user requirements through Order Relation Analysis (ORA) and the Coefficient of Variation (CV) method, so as to extract core design elements. On this basis, three modular table-chair-storage nesting set design schemes were developed. The VlseKriterijumska Optimizacija I Kompromisno Resenje (VIKOR) method was further adopted to conduct comprehensive multi-criteria evaluation and verify the rationality and applicability of the optimal design scheme. The proposed research framework not only ensures the scientificity and systematicness of the age-friendly furniture design process, but it also improves the practical application value of the research results.

Age-friendly Furniture Design

Research on the adaptability of furniture for the elderly in the international context has been continuously deepening. The research focus mainly lies in the analysis of the behavioral characteristics of the elderly, as well as the application of human factors engineering design for adaptive furniture, *etc.* At the same time, it also continuously expands the frontier exploration of intelligent furniture and elderly-friendly furniture (Fabisiak *et al.* 2021). A systematic analysis was conducted on the mobility level of the elderly and their body measurements, providing quantitative data support for the structural design and functional configuration of age-friendly seats (Xiong *et al.* 2025). This helps to reduce the usage risks and enhance the autonomy of the elderly in their home lives (Jin *et al.* 2026). From the perspectives of the material characteristics of furniture and visual perception, the design should fully take into account the usage experience and emotional demands of elderly users, and incorporate the dual attributes of psychological comfort and human-computer friendliness into the products (Zhang *et al.* 2025). By means of focusing on the direction of intelligent elderly-friendly furniture and integrating the ergonomics characteristics of the elderly with intelligent technology, a more humanized and personalized smart home experience is constructed, further expanding the design dimension of elderly-friendly furniture.

Despite these advancements, existing literature mostly has focused on single dimensions such as space renovation, furniture function, or technology application, with limited attention given to the specific scenario of compact apartments. Current design methodologies lack a systematic pathway for translating demands into design features within this scenario and do not adequately consider the spatial constraints of small urban dwellings (Chang *et al.* 2025). Demand identification often remains at the level of qualitative synthesis, with a lack of standardized approaches for assigning quantitative weights and element priorities, resulting in limited comparability. Moreover, solution evaluation primarily relies on principles and case studies, lacking systematic decision-making based on multiple criteria and validation by the target users.

To bridge these gaps, this study focuses on furniture solutions for compact elderly care apartments. First, it systematically extracts the needs of elderly users using the AD. Then, it introduces ORA and the CV method to obtain comprehensive weights that balance subjective and objective factors, driving the design of age-friendly furniture for space-constrained environments (Ren *et al.* 2025). During the design phase, modular prototypes of three living room furniture configurations are developed. Finally, VIKOR is applied for multi-criteria optimization of the design (Wen *et al.* 2025), and expert evaluation and ergonomic simulation. This approach strengthens the quantitative decision-making and empirical testing of age-friendly furniture for compact spaces.

Modular Furniture Design

Modular design is an effective strategy for addressing spatial constraints in compact living environments and the need for adaptive functional transitions (Chang *et al.* 2025). Its versatility and component interchangeability facilitate mass production and reduce maintenance costs (Sawyer *et al.* 2025). Zheng and Shen (2025) emphasized that modular furniture, through its disassembly and reconfiguration capabilities, adapts to diverse changes in spatial form and functional needs. This approach improves user comfort and efficiency while effectively reducing lifecycle costs, increasing space utilization, and enhancing user satisfaction. A case study by Mu'az *et al.* (2022) confirmed that modular design can improve material utilization and extend furniture lifespan, aligning closely with sustainable development principles. Kuys *et al.* (2021) found that integrating human-centered design methods with holistic sustainable design principles can accurately match user needs, drive product innovation, and contribute to the sustainable development of local manufacturing ecosystems. Additionally, Wang (2022) analyzed the sustainable application of modular furniture, proposing that the flexible interchangeability of decorative modules can achieve stylistic diversification, thereby providing a new perspective on the contextual adaptability of modular design.

However, existing literature has predominantly focused on aesthetics or commercial display design, lacking specific consideration of the ergonomic and functional requirements of the elderly population. Furthermore, the selection and iteration of solutions often rely on subjective designer experience or single indicators, lacking a systematic multi-criteria decision-making framework. To address these limitations, this study, within a modular design framework, prioritizes the needs of the elderly. Using structural stability and fall prevention as key constraints, the research deconstructs the structural support, seating, mobility, and storage modules of living room tables and chairs. In design decisions, a comprehensive weighting calculation is employed, and the evaluation dimensions cover space efficiency, operational effort, comfort, and safety, thereby generating an adaptive configuration suitable for compact elderly care scenarios (Wang *et al.* 2025).

Application of Multi-Criterion Evaluation in Furniture Design

In the field of design evaluation and alternative selection, Multi-Criteria Decision-Making methods are widely implemented (Qu *et al.* 2025). Tian *et al.* (2018) employed the Analytic Hierarchy Process (AHP) to transform user needs into design characteristics, facilitating a mapping from users to products and providing accurate, effective, and systematic decision support for product evaluation. Similarly, Xie *et al.* (2024) combined fuzzy evaluation theories to rank various furniture design alternatives, providing a scientific basis for product optimization. These methods emphasize the systematic and quantifiable nature of the design decision-making process (Qin *et al.* 2025). Buchert *et al.* (2014) investigated the application of diverse methodologies throughout the furniture design process, deriving process-based selection strategies. By clarifying the specific outputs of each method, they allocated product design methods to different stages of the creation workflow and evaluated their efficacy. Hao and Guan (2025) integrated landscape aesthetics assessment methods with Kansei Engineering. They analyzed users' visual and emotional preferences by collecting image aesthetic scores and emotional assessment data, thereby providing guidance for design optimization.

Despite these contributions, several limitations persist in existing literature. First, the integration of subjective and objective weights is often insufficient, which can easily lead to evaluation results being biased towards subjective expert experience. Second, the processing of user survey data is often oversimplified, which may introduce bias. Finally, many studies lack feedback verification from real users, resulting in a disconnect between the evaluation system and actual user experience. To address these limitations, this study adopts an integrated weighting strategy utilizing ORA and the CV method in the demand quantification stage. This approach mitigates the impact of scale and extreme values on weight estimation. In the solution decision-making stage, it introduces the VIKOR method's concept of closeness to the ideal solution to balance maximum group utility and minimum individual regrets. Such an approach improves the robustness and reproducibility of multi-criteria evaluation in furniture design scenarios.

EXPERIMENTAL

Proposed Framework

This study proposes a systematic framework for the design and optimization of modular table-chair-storage nesting sets tailored to home-based elderly care in compact apartments. It aims to identify core user demands, implement modular design strategies, construct a scientific decision-making model, and conduct ergonomic validation. The overall technical roadmap is illustrated in Fig. 1, which consists of five sequential research phases.

Phase 1: Data Acquisition and Classification. User needs regarding the modular table-chair-storage nesting set for home-based elderly care in compact apartments were systematically collected through literature review, market research, and questionnaire surveys. The AD method was adopted to categorize unstructured demand information according to logical correlations and attribute similarities. Key functional demands and design pain points were further summarized, laying a foundation for subsequent weight calculation and scheme optimization.

Phase 2: Determination of Requirement Weights. To rank the age-friendliness and space-adaptability requirements of modular table-chair-storage nesting sets for elderly families in compact apartments, this study adopted a comprehensive weighting method. Subjective weights were calculated using ORA. Based on the preliminary analysis, core demands were identified, and eight experts were invited to rank their importance. The subjective weights were then calculated and normalized according to the relative importance ratios of adjacent criteria. Meanwhile, objective weights were calculated using the CV method. Finally, the comprehensive weights were determined using a linear combination approach. The final weight ranking clarifies the priority of key demands, providing a reliable basis for the formulation of modular design strategies.

Phase 3: Modular Concept Development. Based on the prioritized demands and design requirements for age-friendly furniture in compact apartments, three modular table-chair-storage nesting set configurations were developed. Each configuration details functional module decomposition, assembly mechanisms, age-friendly safety measures, and space utilization strategies.

Phase 4: Multi-Criteria Evaluation. An evaluation index system was established based on demand categories and their comprehensive weights, summarizing the core indicators of age-friendly furniture for compact spaces. An evaluation panel of 8 experts scored each modular table-chair-storage nesting set alternative on a 7-point Likert scale, and the average score was used as the design performance data. The VIKOR method was applied to calculate the ranking index of each design, thereby determining the optimal design.

Phase 5: Experimental Verification. The final optimized solution was evaluated using Jack simulation to verify reachability, operational feasibility, lumbar load, and postural comfort.

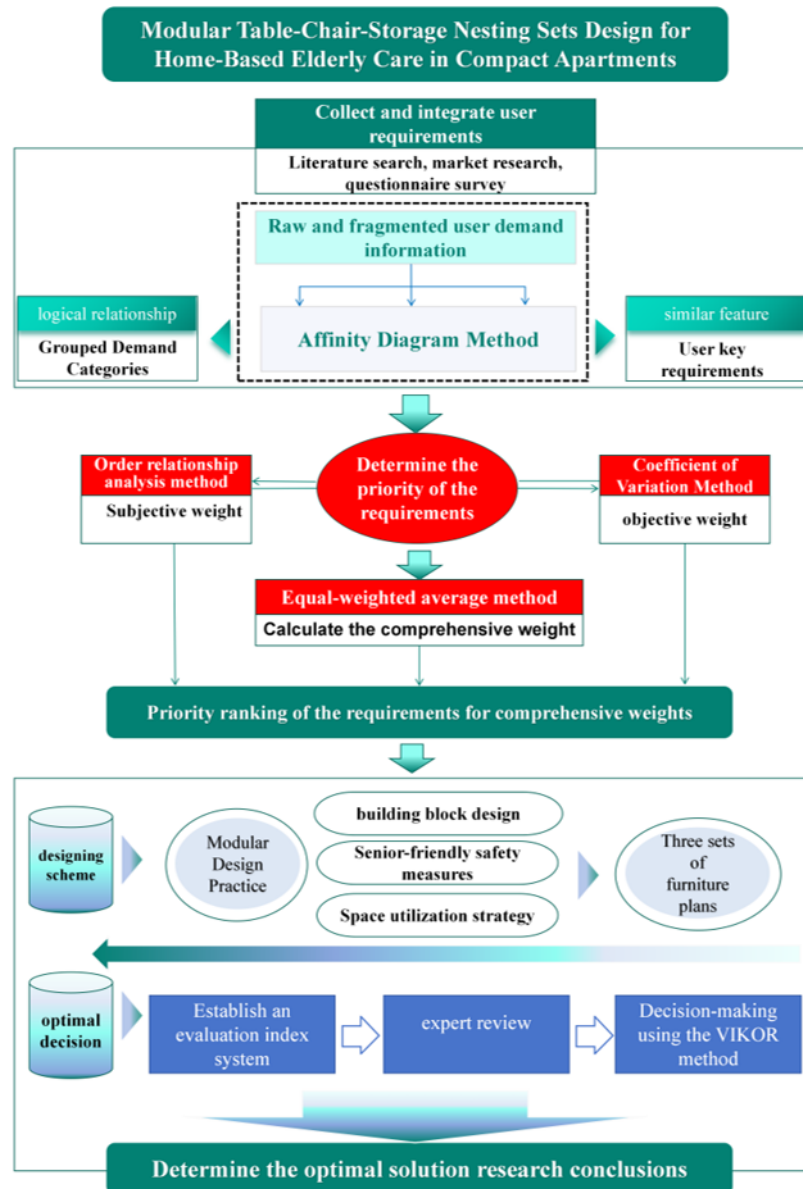


Fig. 1. Proposed framework

Affinity Diagram Method

The AD, proposed by Japanese scholar Jiro Kawakita, serves as a systematic analytical tool optimized for qualitative data processing. Its primary mechanism involves synthesizing inherent connections between scattered information among fragmented information to categorize and refine discrete perspectives (Scupin 1997). Consequently, this process constructs thematic clusters within a hierarchical structure. The AD method is particularly efficacious in handling ambiguous and unstructured research scenarios. In this study, the application of the AD follows a three-stage process involving data collection, expert validation, and thematic clustering. First, the usability challenges, spatial adaptability issues, and functional requirements of age-friendly modular table-chair-storage nesting sets in compact living scenarios were systematically collected through comprehensive surveys. After anonymization, the discrete data were encoded into standardized statements to lay the foundation for subsequent analysis. Experts were invited

to verify the reliability and relevance of the data and to complete categorization. Finally, thematic clustering was conducted on the integrated demand information to extract core elements and clarify the hierarchical relationships among them.

Order Relation Analysis Method

ORA is a subjective weighting technique that determines weights by establishing a ranking order of evaluation criteria based on expert judgments (Kondratyev *et al.* 1998). In this study, ORA was applied to quantify the priority of core design requirements, establishing a systematic link between qualitative requirement clustering and quantitative decision-making. The specific steps are as follows:

Step 1: Based on the criteria extracted using the AD method, the core requirements for clustering are refined, and the order relationship is determined. Let n indicators be labeled $X_1, X_2, \dots, X_n$, and through expert review, the order relationship of each furniture indicator is determined as follows.

$$X_1 > X_2 > \dots > X_n \quad (1)$$

Step 2: The next step is to determine the importance ratio of adjacent indicators, based on expert judgment of the importance of X_k adjacent indicators X_{k-1} ,

$$r_k = \frac{w_{k-1}}{w_k}, \quad k=2, \dots, n \quad (2)$$

where the r_k values are referenced in Table 1.

Table 1. Reference Values for r_k Assignment

r_k	Description (Definition of Relative Importance)
1.0	Criterion X_{k-1} has equal importance to criterion X_k
1.1	Criterion X_{k-1} is slightly more important than criterion X_k
1.3	Criterion X_{k-1} is significantly more important than criterion X_k
1.5	Criterion X_{k-1} is strongly more important than criterion X_k
1.7	Criterion X_{k-1} is extremely more important than criterion X_k

Step 3: Weight Coefficient Calculation. Based on the values provided by the experts r_k , first calculate the weight of the lowest-ranked indicator w_n .

$$w_n = \frac{1}{1 + \sum_{k=2}^n \prod_{i=k}^n r_i} \quad (3)$$

The next step is to calculate the weights of all indicators in sequence:

$$w_{k-1} = r_k w_k \quad (k=n, n-1, \dots, 2) \quad (4)$$

The standardized subjective weight vector $w^{ORA} = w_1, \dots, w_n$ satisfies the requirements $\sum_{j=1}^n w_j = 1$.

Coefficient of Variation Method

The CV method is an established objective weighting approach. Its underlying principle postulates that the greater the criterion values among different alternatives, the stronger its capability to distinguish the performance of the alternatives. Consequently, such criteria possess higher discriminatory power and information content, warranting the

assignment of a higher weight.

Step 1: Construct the decision matrix. Given m alternatives and n criteria, the initial decision matrix is defined as $X=[x_{ij}]_{m \times n}$. Here, x_{ij} represents the original value of the i -th alternative regarding the j -th criterion.

Step 2: Calculate the mean and standard deviation. To analyze the central tendency and dispersion of each criterion, calculate the mean ($\bar{x}_j$) and standard deviation (S_j) of the j -th criterion using Eqs. 5 and 6,

$$\bar{x}_j = \frac{1}{m} \sum_{i=1}^m x_{ij} \quad (5)$$

$$S_j = \sqrt{\frac{1}{m-1} \sum_{i=1}^m (x_{ij} - \bar{x}_j)^2} \quad (6)$$

where the mean represents the average level of the j -th criterion, and the standard deviation reflects the degree of deviation of each alternative from the mean. The use of $m-1$ as degrees of freedom ensures an unbiased estimate of the standard deviation.

Step 3: Calculate the coefficient of variation. The CV (v_j) is the ratio of the standard deviation to the mean, used to eliminate the scaling effects caused by different dimensions and magnitudes. The formula is expressed as follows.

$$v_j = \frac{S_j}{\bar{x}_j} \quad (7)$$

The larger the value of v_j , the higher the relative dispersion of the j -th criterion. This indicates a more significant difference between different alternatives on this criterion, implying stronger distinguishing effect on the evaluation results; therefore, a higher weight should be assigned.

Step 4: Determination of objective weights. The coefficients of variation of all criteria were normalized to obtain the objective weight (w_j^{CV}) of the j -th criterion.

$$w_j^{CV} = \frac{v_j}{\sum_{k=1}^n v_k}, j=1, \dots, n \quad (8)$$

Step 5: Integration of Subjective and Objective Weights. Combining the subjective weights (w_j^{ORA}) obtained from ORA, the arithmetic mean method is used to integrate the subjective and objective weights to obtain the comprehensive weight (w'_j) of the j -th criterion.

$$w'_j = \frac{w_j^{ORA} + w_j^{CV}}{2} \quad (9)$$

VIKOR Method

The VIKOR method is a multi-criteria decision-making approach based on the concept of compromise solutions (Opricovic & Tzeng, 2004). Its core idea is to rank the optimal solutions by calculating the degree of closeness of each alternative to the positive ideal solution and the negative ideal solution. In the decision-making process of the modular furniture design for small-sized home-based elderly care in this study, the VIKOR method has significant advantages over existing methods: Compared with the AHP method that focuses on hierarchical decomposition and subjective weighting, it places greater emphasis on forming an effective decision consensus under the condition of multiple conflicting

objectives (Anme *et al.* 2013), enhancing the practical feasibility of the solutions. Compared with the TOPSIS method that also relies on the proximity to the ideal solution, it can better balance the maximization of group utility and the minimization of individual regret, thereby obtaining a compromise optimal solution acceptable to the decision-makers. This method perfectly aligns with the diverse and complex scenario characteristics of modular furniture design for small-sized home-based elderly care, as it maximizes the overall utility while minimizing individual regret (Lin *et al.* 2025). In this study, the comprehensive weight (w_j) and priority ranking of each criterion are determined based on ORA and the CV method. The optimal solution for modular furniture design is selected by ranking through the VIKOR method. Assuming there are m alternative ($A_1, A_2, \dots, A_m$) solutions and n evaluation criteria, the original scores have been normalized to obtain the standardized decision matrix $R = (r_{ij})_{m \times n}$, where r_{ij} is the standardized value of alternative i regarding criterion j . The computational procedure is detailed below.

Step 1: The best value (f_j^+) and the worst value (f_j^-) for each criterion are determined using Eqs. 10 and 11,

$$f_j^+ = \max_i r_{ij} \quad (10)$$

$$f_j^- = \min_i r_{ij} \quad (11)$$

Step 2: Calculate the group utility value (S_i) and the individual regret value (R_i). These values represent the average group score and the worst individual score for alternative i , respectively, calculated using Eqs. 12 and 13,

$$S_i = \sum_{j=1}^n \omega_j \frac{f_j^+ - r_{ij}}{f_j^+ - f_j^-}, i = 1, \dots, m \quad (12)$$

$$R_i = \max_{1 \leq j \leq n} \left(\omega_j \frac{f_j^+ - r_{ij}}{f_j^+ - f_j^-} \right), i = 1, \dots, m \quad (13)$$

where ω_j represents the comprehensive weight of criterion j .

Step 3: Calculate the compromise ranking index (Q_i). The index (Q_i) is calculated using Eq. 14, which integrates group utility and individual regret:

$$Q_i = v \frac{S_i - S^*}{S^- - S^*} + (1 - v) \frac{R_i - R^*}{R^- - R^*} \quad (14)$$

where $S^* = \min S_i$, $S^- = \max S_i$, $R^* = \min R$, and $R^- = \max R_i$. The variable v represents the weight of the strategy of “the majority of criteria” (usually $v = 0.5$).

Step 4: Determine the optimal solution. The alternatives were ranked based on the values of S_i , R_i , and Q_i , in ascending order. The alternative ($A^{(1)}$) with the minimum Q value is proposed as the compromise solution if it satisfies the following two conditions:

Condition 1: Acceptable Advantage.

$$Q(A^{(2)}) - Q(A^{(1)}) \geq \frac{1}{m-1} \quad (15)$$

where $A^{(2)}$ is the alternative with the second lowest Q value.

Condition 2: Acceptable Stability in Decision Making. The alternative $A^{(1)}$ must also be the best ranked by S or R .

If Condition 1 is not satisfied, then the compromise solution set is $\{A^{(1)}, A^{(2)}, \dots, A^{(k)}\}$, where $A^{(k)}$ is determined by $Q(A^{(k)}) - Q(A^{(1)}) < \frac{1}{m-1}$. If only

Condition 2 is not satisfied, then the compromise solution set is $\{A^{(1)}, A^{(2)}\}$. This process ensures the robustness of the final selected modular furniture design.

RESULTS AND DISCUSSION

Requirements Identification and Classification

To extract key terms related to the design of modular table-chair-storage nesting sets for home-based elderly care in compact apartments, the affinity diagram method was adopted in this study. Interviews were conducted with 50 elderly individuals aged 60 years and above with normal cognitive function (25 males and 25 females; see Table 2). Through literature review, market surveys, and interviews, a total of 55 original terms were collected. Eight experts (comprising 3 furniture designers, 2 ergonomics experts, and 3 university product design professors) were invited to categorize and summarize the collected terms. Following data screening and redundancy elimination to ensure comprehensiveness (as illustrated in Fig. 2), 12 effective secondary criteria for modular table-chair-storage nesting sets design in compact elderly care contexts were established. These were subsequently categorized into four primary dimensions (Table 3), providing a basis for the dimensional extraction and weight calculation of design elements.

Table 2. Descriptive Statistics of the Interview Participants

Name	Option	Count	Percentage
Gender	Male	25	50%
	Female	25	50%
Age	60-65	18	36%
	66-70	25	50%
	71-75	4	8%
	75 and above	3	6%
Physical condition	Health autonomy	46	92%
	Restricted movement	4	8%



Fig. 2. Affinity diagram analysis

Table 3. Evaluation Criteria System for Age-Friendly Furniture

Primary Dimensions	Secondary Criteria
Safety Requirements (A)	Structural Stability (A1)
	Operational Safety (A2)
	Material Safety (A3)
Spatial Adaptability (B)	Foldability and Storage (B1)
	Modular Configuration (B2)
Functional Requirements (C)	Mobility and Portability (C1)
	Multifunctionality (C2)
	Ease of Operation (C3)
	Health Support Functions (C4)
	Aesthetic Appeal (D1)
Aesthetic and Form Requirements (D)	Material Texture and Quality (D2)
	Ergonomic Fit (D3)

Calculation of Comprehensive Weight of Design Requirements

Calculation of subjective weights

Based on the AD analysis in the previous section, this study employs ORA to assign weights to the extracted 4 primary dimensions and 12 secondary criteria. This step aims to clarify the importance and weight of each criterion in subsequent design phase.

For the subjective weighting process, a questionnaire survey was conducted involving 8 experts (comprising 3 furniture designers, 2 elderly care institution staff, and 3 university professors specializing in product design). They were invited to score the importance of the secondary criteria listed in Table 3. The scores range from 1 to 9, representing the lowest to the highest level of importance. The scores and average values of the 8 experts for the importance of the 12 criteria are presented in Table 4.

According to the expert scores in Table 4 and the relative importance degrees of

each indicator in Table 5, the ranking of the 12 secondary criteria is determined as follows: $A1 > A2 > C3 > A3 > B2 > D3 > C2 > C4 > B1 > C1 > D2 > D1$. Subsequently, based on the assignment rules in Table 1, the relative importance ratio (r_k) for adjacent criteria is determined, as shown in Table 5. The subjective weights (w_j^{ORA}) are then calculated using Eqs. 1 and 4, and the results are presented in Table 6.

Calculation of objective weights

Based on the expert scoring results in Table 4, a decision matrix is constructed. The standard deviation and mean were calculated using Eqs. 5 and 6. Subsequently, the coefficient of variation was derived using Eq. 7. Finally, the values were normalized using Eq. 8 to obtain the objective weights (w_j^{CV}) for each criterion. The results are shown in Table 7.

Calculation of comprehensive weight

The subjective and objective weights were then integrated. Using the arithmetic mean method, the comprehensive weights for each criterion were calculated. The results, sorted by weight proportion, are presented in Table 8. These rankings provide critical guidance for the subsequent design practice.

Table 4. Expert Scoring Results for Age-Friendly Furniture Design Criteria

Secondary Criteria	Expert 1	Expert 2	Expert 3	Expert 4	Expert 5	Expert 6	Expert 7	Expert 8	Average Score
A1	9	4	9	6	8	9	3	9	7.125
A2	8	5	7	8	9	7	4	8	7.000
A3	7	6	8	7	6	7	5	7	6.625
B1	8	5	6	3	4	8	5	8	5.875
B2	9	6	7	8	5	7	4	5	6.375
C1	7	3	8	6	4	7	3	7	5.625
C2	8	9	5	7	7	4	4	5	6.125
C3	7	8	6	8	7	5	8	6	6.875
C4	6	7	4	6	5	6	7	7	6.000
D1	5	7	5	6	3	5	2	5	4.750
D2	6	4	6	5	4	6	3	5	4.875
D3	7	8	5	7	6	7	5	5	6.250

Table 5. Relative Importance Ratios (r_k) of Adjacent Criteria

Comparison (x_{k-1} VS x_k)	Importance Ratio (r_k)
A1 VS A2	1.3
A2 VS C3	1.7
C3 VS A3	1.1
A3 VS B2	1.3
B2 VS D3	1.3
D3 VS C2	1.3
C2 VS C4	1.5
C4 VS B1	1.5
B1 VS C1	1.3
C1 VS D2	1.3
D2 VS D1	1.3

Table 6. Final Subjective Weight Results

Primary Dimensions	Subjective Weight	Secondary Criteria	Subjective weight
A	0.583	A1	0.267
		A2	0.206
		A3	0.110
B	0.107	B1	0.022
		B2	0.085
C	0.222	C1	0.017
		C2	0.050
		C3	0.121
		C4	0.033
D	0.088	D1	0.010
		D2	0.013
		D3	0.065

Table 7. Calculation Results of Objective Weights

Primary Dimensions	Objective Weight	Secondary Criteria	Mean	Standard Deviation	CV	Objective Weight
A	0.236	A1	7.125	2.475	0.347	0.113
		A2	7.000	1.690	0.241	0.078
		A3	6.625	0.916	0.138	0.045
B	0.194	B1	5.875	1.955	0.333	0.108
		B2	6.375	1.685	0.264	0.086
C	0.326	C1	5.625	1.996	0.355	0.115
		C2	6.125	1.885	0.308	0.100
		C3	6.875	1.126	0.164	0.053
		C4	6.000	1.069	0.178	0.058
D	0.244	D1	4.750	1.581	0.333	0.108
		D2	4.875	1.126	0.231	0.075
		D3	6.250	1.165	0.186	0.061

Table 8. Comprehensive Weighting Results and Ranking

Primary Dimensions	Comprehensive Weights	Secondary Criteria	Comprehensive Weights	Rank
A	0.410	A1	0.190	1
		A2	0.142	2
		A3	0.078	5
B	0.150	B1	0.065	8
		B2	0.085	4
C	0.273	C1	0.066	7
		C2	0.075	6
		C3	0.087	3
		C4	0.046	11
D	0.166	D1	0.059	10
		D2	0.044	12
		D3	0.063	9

Design of Modular Table–Chair–Storage Nesting Sets

Guided by the ranking results of the aforementioned secondary criteria, three modular table-chair-storage nesting sets configurations were developed, as shown in Figs. 3, 4, 5 and 6.

Solution 1: This configuration adopts a modular structure. The core consists of “independent seating units and the central hub”. The overall table and chairs have been optimized for light-weight nature and reduced mobility difficulty, making them suitable for the operation of the elderly. The two independent seating modules can be used separately as lounge chairs. The opening and closing are achieved through methods such as pulling and sliding, which are effortless. The elderly can operate them independently. Each seating module is equipped with a pull-out single-person small seat, which can be used in combination or stored separately. The seating module, the central hub, and the tabletop can be quickly connected to form a dining table, suitable for various scenarios. The main material is selected as light-weight and light-colored solid wood, with matte finish to reduce glare and alleviate visual fatigue. The touch is smooth and durable. The seats are equipped with breathable ergonomic cushions. The central hub has an open storage space. It balances comfort and convenience. The height of the table and chairs is optimized based on the body measurement data of the elderly, reducing physical burden. The bottom of the module is equipped with an anti-tip limit structure, which takes into account flexible combination, independent operation, and safety of use, and is suitable for small-sized home-based elderly care scenarios.

Solution 2: This design includes a dining table and two chairs. To ensure the structural safety, the table and chair modules adopt light-weight solid wood frames. Each module weighs within the range that an elderly person can move with one hand. Combined with anti-slip and wear-resistant pads at the bottom, they can be smoothly pushed and placed on small-sized floor surfaces, enabling independent and autonomous operation. All the edges of the components are rounded for smooth transition, avoiding the risk of bumps. The seats are equipped with arc-shaped ergonomic armrests, facilitating the elderly to stand up and sit down, reducing the risk of falls. The seats are equipped with high-density pressure-reducing cushions, which can optimize the distribution of sitting pressure. The lower part of the chair integrates a storage box, and a hidden pull-out storage unit is added under the tabletop to achieve a dual improvement in functionality and space utilization. The height of the table and chairs is adapted to the physiological characteristics of the

elderly for human-machine compatibility, effectively relieving physical fatigue. The entire module can be fully nested and stored, significantly reducing the occupied space, and is suitable for various scenarios such as dining, hosting guests, and relaxation.

Solution 3: This design is intended to meet the daily needs of elderly people living alone. It adopts a fixed and compact layout of “one table and two chairs”, which is suitable for scenarios of “eating alone and relaxing comfortably”. This design simplifies the complexity of the layout in compact apartments; the elderly can independently complete folding, unfolding, and space adjustment. The chairs are designed with an all-inclusive embedded style, which can be fully retracted under the table to free up activity space; the tabletop has a single-sided folding structure, and when unfolded, it can expand the usable area to meet temporary dining or leisure needs. Open storage compartments are set under the table to facilitate the convenient storage of utensils, tissues, *etc.* On the top of the backrest of the chair, an integrated grip handle is set, with a shape that conforms to human grasping habits, allowing the elderly to easily lift, move the seat module, and achieve autonomous layout adjustment without assistance. All exposed edges are rounded and smoothed, and the table body adopts a wide base structure, significantly enhancing overall stability and anti-overturning performance. This solution uses a minimalist modular logic to lower the operational threshold, while taking into account spatial flexibility and the independent usage ability of the elderly, especially suitable for temporary space conversion and daily multi-functional use in small-sized apartments.



Fig. 3. Modular Table-Chair-Storage Nesting Sets schemes for home-based elderly care in compact apartments

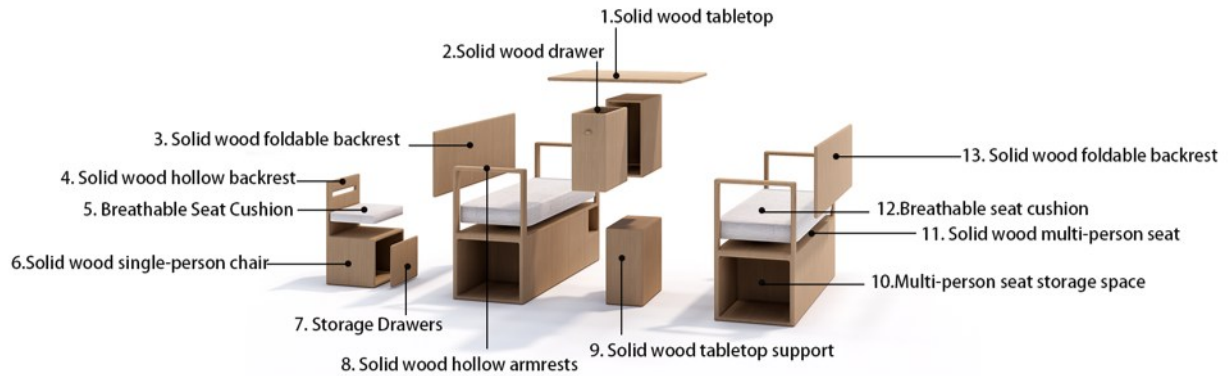


Fig. 4. Component illustration of Option 1

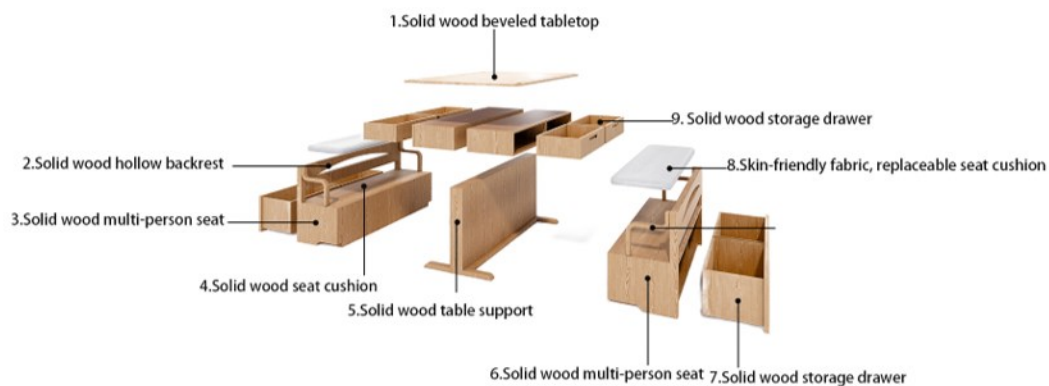


Fig. 5. Component illustration of Option 2

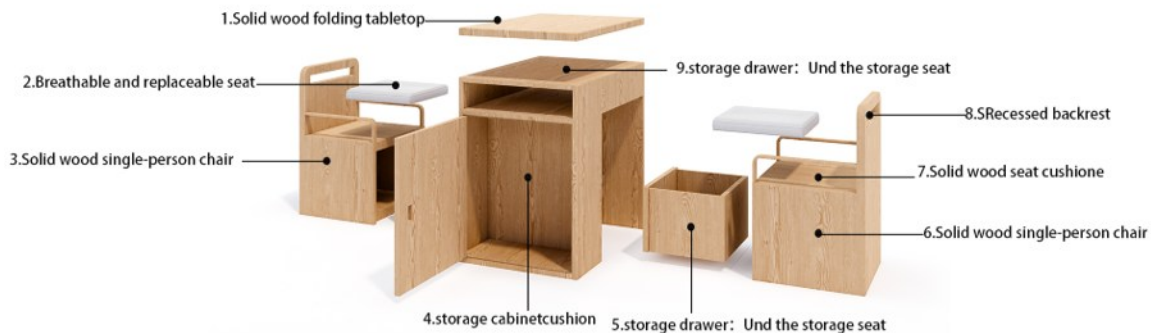


Fig. 6. Component illustration of Option 3

Scheme Evaluation and Optimization

Construction of the initial decision matrix

Based on the established evaluation criteria system for modular table-chair-storage nesting sets in compact elderly care apartments (Table 3), a panel consisting of 3 furniture designers, 2 elderly care professionals, and 3 product design university professors evaluated the three design schemes. They utilized a 7-point Likert scale to assign scores to the 12 secondary criteria. Subsequently, the average scores were calculated. All evaluation criteria in the system are classified as benefit-type criteria. The initial evaluation values of the schemes were obtained, and the initial decision matrix was established as shown in Table 9.

Calculate the group utility, individual regret, and compromise index

The values of S_i , R_i , and Q_i were computed according to Eqs. 10 through 14, respectively. The comprehensive weights (w_j) derived in Table 8 were applied in the calculation. The evaluation results of the design schemes are shown in Table 10. The schemes are ranked from smallest to largest according to their compromise ranking index: Scheme 1 > Scheme 3 > Scheme 2.

Table 9. Initial Evaluation Matrix of the Design Schemes

Criteria	Scheme 1	Scheme 2	Scheme 3
A1	6.5	5.8	5.9
A2	5.6	5.7	5.5
A3	6.1	5.9	6.1
B1	6.8	6.0	5.7
B2	6.2	5.8	6.1
C1	6.1	5.5	5.8
C2	6.5	6.0	5.7
C3	6.2	5.9	5.8
C4	6.4	6.5	5.9
D1	6.3	5.9	5.6
D2	6.2	5.7	6.2
D3	6.2	5.9	6.5

Table 10. VIKOR Evaluation Results

Alternative	Group utility	Individual Regret	Compromise Index	Rank
Scheme 1	0.1102	0.0710	0.0000	1
Scheme 2	0.7191	0.1900	1.0000	3
Scheme 3	0.6911	0.1629	0.8630	2

Determine the optimal solution

According to the VIKOR method, the compromise values are ranked in ascending order: Scheme 1, Scheme 3, Scheme 2. Since $Q(A^{(2)}) - Q(A^{(1)}) \geq \frac{1}{m-1} (m=3)$, it satisfies condition 1. The $A^{(2)}$ value of is the best ranking among the values S_i , satisfying R_i both condition 1 and condition 2. Consequently, Scheme 1 is determined to be the robust optimal solution.

Based on the global trend of population aging and considering the demands of the elderly for elderly care living environments and furniture functions, this study has systematically sorted out and identified core demands through interviews and market research, verifying the practical necessity of modular table and chair storage sets with high space utilization and usability. Meanwhile, various methods such as the affinity diagram were adopted in the design practice, which fully accommodated the diverse needs of the elderly for home-based elderly care furniture and also ensured the reliability of the design scheme, providing solid support for practical engineering applications. In addition, the VIKOR method was used for multi-criteria decision-making, which further enabled scientific optimization and selection of schemes, thereby deriving the optimal design solution that better meets the demands.

Ergonomic Simulation and Experimental Verification

In a Jack virtual simulation experiment, virtual human models and real home scenarios were constructed to simulate daily tasks. For Scheme 1, the software was adopted to analyze the elderly's daily operation behaviors and motion trajectories in real contexts, and the data obtained during operation were used to support design optimization. The human-machine simulation reachability map (Fig. 7) serves as a critical bridge connecting human physical capabilities and mechanical performance. Its core value lies in optimizing the modular table-chair-storage nesting set design. chair, storage, and nesting set design through digital means. By constructing the virtual human reachable domain, it simulates the range of daily use, operational efficiency, safety, and comfort for the elderly, thereby enhancing the satisfaction of furniture usage.

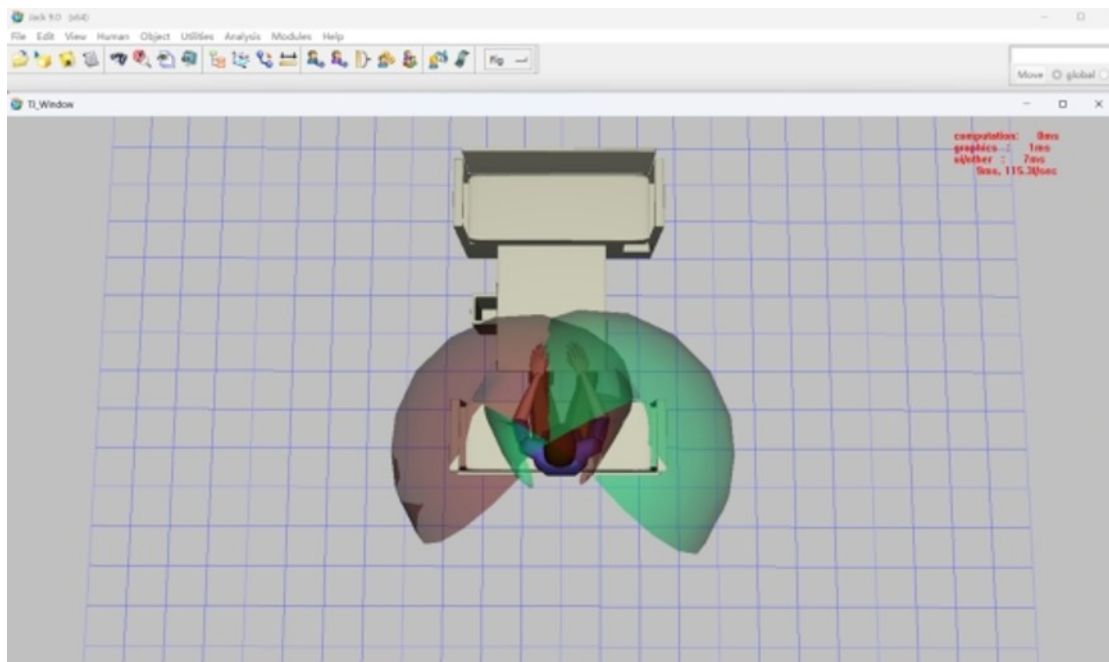


Fig. 7. Analysis of the Reachable Domain in Human-Machine Simulation

One of the key points of the ergonomic simulation experiment is to simulate the compression on the lumbar spine of the elderly during the use of the seat. Through the lower back analysis tool of the Jack software (Fig. 8), the pressure on the lumbar spine (L4/L5) of the lower back is analyzed. Figure 8 shows that the pressure on the lumbar L4/L5 is 538 Newtons, which is lower than the 3400 Newtons limit for lumbar compression specified by the National Institute for Occupational Safety and Health of the United States. Therefore, it can ensure the safety of the elderly during the use of the seat and meet the requirements of ergonomics.

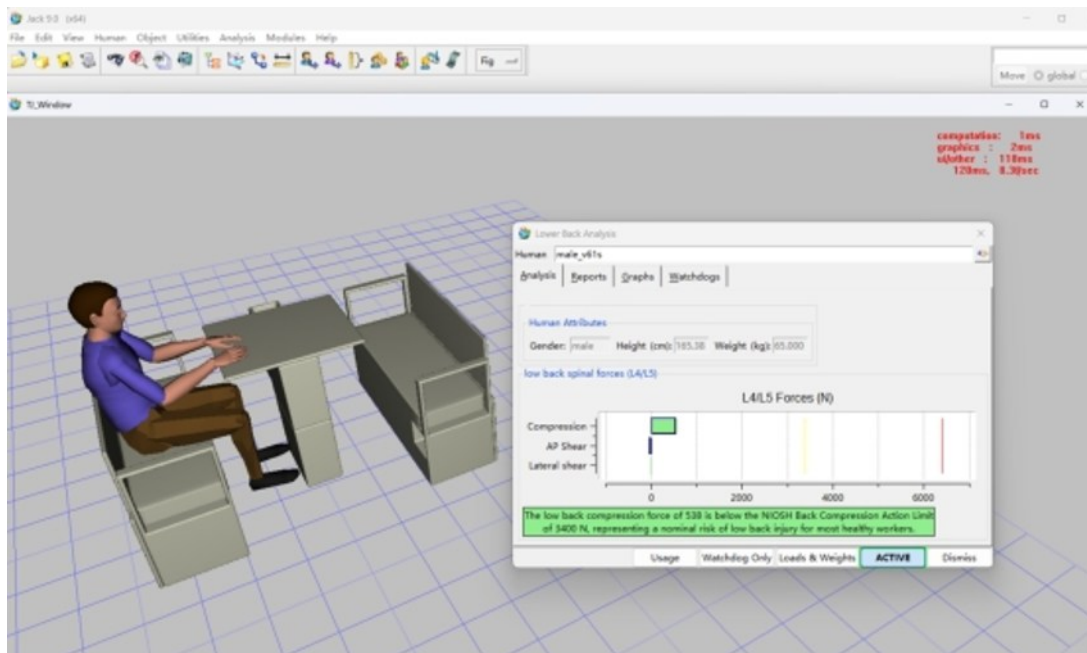


Fig. 8. Dynamic analysis of lumbar spine stress

In the comfort evaluation of the modular desk-chair storage system used by the elderly, the “comfort assessment” tool was employed to analyze the users’ sitting postures. The scoring range of this tool is from 0 to 80 points, with higher scores indicating lower comfort levels. As shown in Fig. 9, the neck score was 20.2, the shoulder score was 8.6, the back and left and right upper limbs were both 0, the hip score was 29.2, the left leg score was 16.0, the right leg score was 15.9, and the fatigue score was 38.1. The overall comfort score was 36.9. The assessment results for each part were all below the 60-point threshold, thus meeting the 60-point critical value requirement of general literature and conforming to ergonomic requirements.

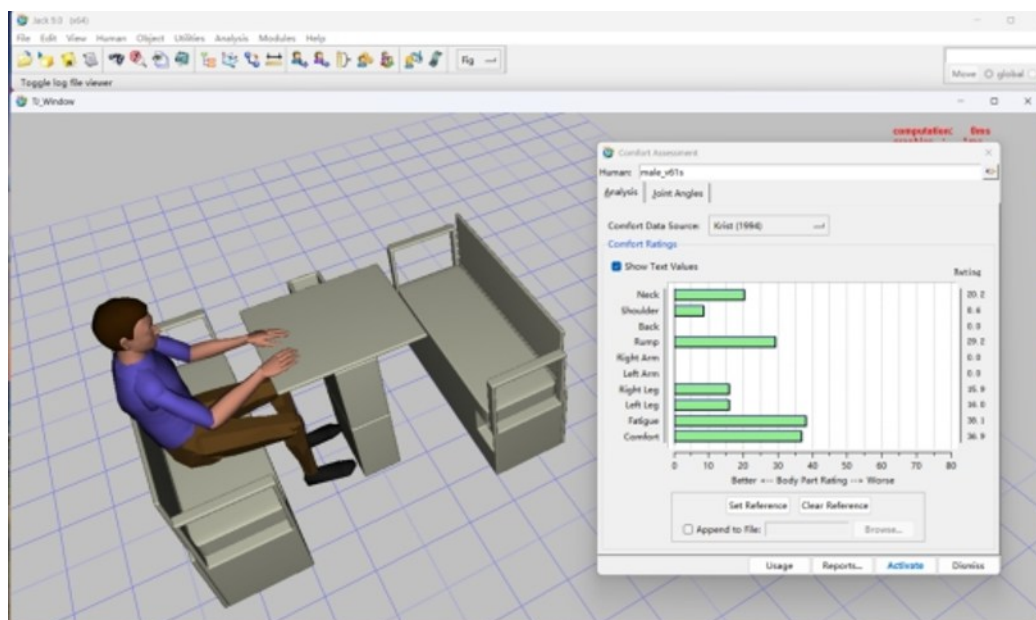


Fig. 9. Human comfort level test

Based on the above simulation results, Scheme 1 demonstrates excellent performance in terms of human-machine ergonomics. The human-machine ergonomics analysis results fully show that this scheme has superiority in terms of comfort, safety, and operational compatibility, and it can provide a reliable basis for the subsequent optimization and use of the product.

CONCLUSIONS

1. By employing the affinity diagram (AD) method to synthesize and organize user requirements, this study established a design evaluation criteria system for age-friendly furniture in compact apartments, which includes 12 criteria such as material safety, operational safety, foldability, and modular design. Subsequently, by using order relation analysis (ORA) and the coefficient of variation (CV) method to integrate subjective and objective weights, the study identified structural stability, operational safety, ease of operation, material safety, and modular configuration as the core criteria in this field. These findings provide key guidance for the design of age-friendly furniture in compact living environments. Specifically, optimizing usability and operating mechanisms while enhancing the flexibility and adaptability of modular design can effectively realize “multifunctional utilization” and dynamic spatial adaptation.
2. A comprehensive evaluation of the three design alternatives was conducted using the VIKOR method. The results demonstrate that Scheme 1, with its innovative modular structure, optimally satisfies the core needs and practical application scenarios of age-friendly furniture for compact apartments. The core advantages of this scheme lie in the synergistic optimization of functional adaptability, age-friendly safety, and space efficiency. By integrating independent seating modules with a central hub, the design facilitates flexible transitions between solitary and social scenarios. Furthermore, the incorporation of ergonomic dimensions, anti-tip mechanisms, and integrated storage solutions ensures a critical balance between comfort, safety, and spatial utilization, thereby validating the effectiveness of the proposed design strategy.
3. This study integrated AD, ORA, CV, and VIKOR analyses to establish a scientific and systematic quantitative framework for designing modular table-chair-storage nesting sets for home-based elderly care in compact apartments, thereby offering a valuable theoretical reference for related research. Through the case study of living room furniture, the theoretical model was verified. The results indicate that the proposed integrated methodology can systematically analyze core user needs, enabling designers to accurately grasp critical requirements and demonstrating high efficacy in prioritizing user needs and optimizing design decision-making.

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