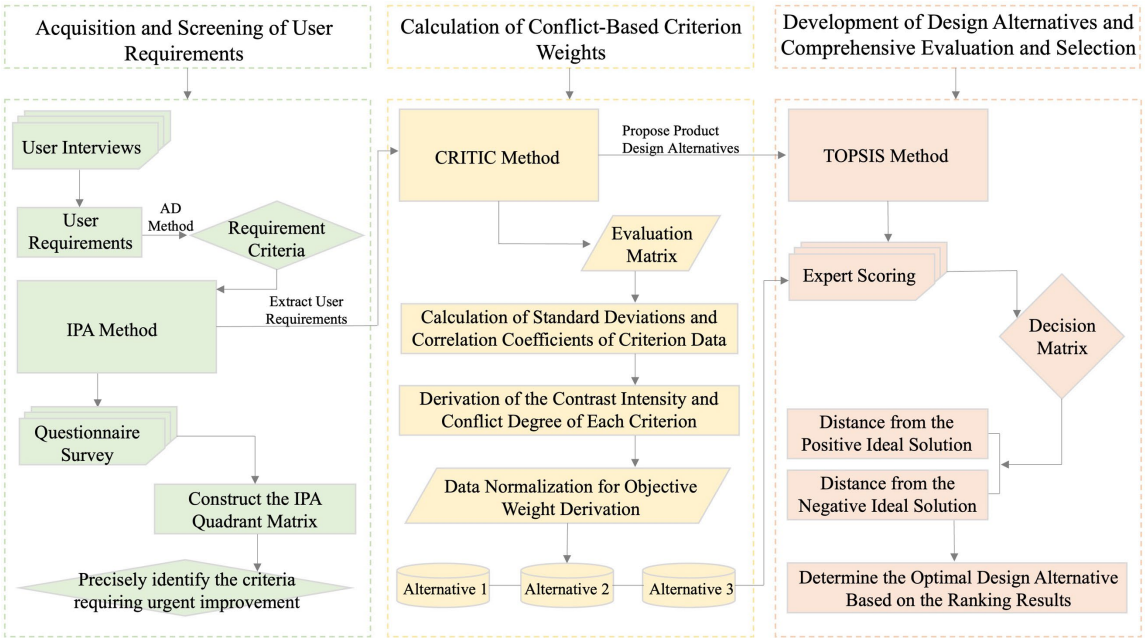
Optimization of Modular Wardrobe Design Using an Integrated IPA-CRITIC-TOPSIS Approach

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GRAPHICAL ABSTRACT



Optimization of Modular Wardrobe Design Using an Integrated IPA-CRITIC-TOPSIS Approach

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Compact living is becoming more common and thus the demand for personalized solutions has increased. Conventional wardrobes with fixed structures increasingly fail to meet users' needs for clothing storage and spatial adaptability across life stages. Therefore, this study proposes an IPA-CRITIC-TOPSIS-based method to improve wardrobe space utilization while accommodating users' dynamic storage requirements. First, modular wardrobe design criteria were derived from user interviews, an analysis of modular furniture design characteristics, and affinity diagramming (AD). Importance-performance analysis (IPA) was then applied to identify key criteria requiring priority improvement. Subsequently, the Criteria Importance Through Intercriteria Correlation (CRITIC) method was used to calculate information-based weights, thereby capturing the information content and intercriterion conflict embedded in the current evaluation matrix. Based on these findings, three modular wardrobe design alternatives were developed. The Technique for Order Preference by Similarity to an Ideal Solution (TOPSIS) was then introduced to comprehensively rank and select the optimal alternative among multiple modular configuration schemes. The results indicate that damage-free assembly and disassembly, corner-space utilization, internal functional zoning, adjustability of storage accessories, and ease of clothing access and retrieval received the highest weights. The refined zoning-oriented alternative was identified as the optimal solution, and its ranking remained stable across different weighting scenarios.

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Keywords: Modular wardrobes; Wooden furniture; User requirements; Design decision-making

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INTRODUCTION

Global urbanization continues to accelerate, and high-density housing and small apartments have become dominant residential forms in contemporary cities. In living environments with limited space, the rational allocation of household storage space plays a critical role in improving residents' quality of life and overall living experience (Marco 2022). As a core furniture element in residential environments, the wardrobe not only performs the basic function of clothing storage but also plays a key role in maintaining visual order and reducing the burden of daily household tasks. However, conventional fixed wardrobes often fail to accommodate storage needs that vary across life stages and seasons, primarily because their internal structures are established in advance and difficult to modify (Daglio *et al.* 2023). The organization of internal wardrobe space directly affects

the efficiency of clothing classification, ease of access and retrieval, and the perceived orderliness of the space. Therefore, optimizing wardrobe design through systematic research methods to better accommodate users' storage needs across different life stages has become a central issue in modern furniture design and manufacturing. In recent years, space-saving modular furniture design for residential contexts has become an important means of supporting compact living and advancing sustainable development goals (Bang and DeLong 2022). Previous research proposed that the use of capsule wardrobes can influence personal clothing management and promote sustainable development at the individual user level. To identify users' core requirements for wardrobe design, previous research work has integrated the Decision-Making Trial and Evaluation Laboratory (DEMATEL) method with the analytic hierarchy process (AHP) to reveal the feedback mechanisms between functional modules and user experience, thereby effectively prioritizing user requirements (Li *et al.* 2025). Other studies have focused on growth-adaptive children's wardrobes and proposed age-tailored modular configuration strategies by integrating the analytic hierarchy process (AHP) with the entropy weight method (EWM) (Chen and Zhang 2025). Although these studies provide valuable references for quantifying user requirements and formulating design strategies in modular wardrobe design, they often overlook the potential conflicts and correlations among evaluation criteria and rely heavily on experts' subjective ratings to determine criterion weights. In addition, they do not clearly reveal the gap between users' perceived importance of product attributes and the actual performance of existing products.

To address these limitations, this study proposes an IPA-CRITIC-TOPSIS-based framework to optimize modular wardrobe design through a scientific decision-making process. The framework responds to changing user requirements caused by variations in family composition, seasonal clothing storage, and clothing categories, thereby enhancing the sustainability of product use. First, 12 target users were recruited for semi-structured interviews and field observations. The Affinity Diagram (AD) method was then applied to semantically refine and cluster the interview data, leading to the development of 18 design requirement criteria. Second, a questionnaire was developed based on the importance-performance analysis (IPA) framework. A total of 136 questionnaires were distributed, and 128 valid responses were obtained. Twelve high-priority design criteria were identified and further classified into four primary design criteria. Subsequently, the Criteria Importance Through Intercriteria Correlation (CRITIC) method was used for objective weighting, and three modular wardrobe design alternatives were developed according to the resulting criterion weights. Finally, a 10-member panel comprising design experts and target users was recruited to conduct a comprehensive evaluation using the technique for order preference by similarity to an ideal solution (TOPSIS), thereby selecting the optimal design alternative. Through constructing and validating this model, this study provides a more rigorous for design decision-making in customized wardrobe design for compact living spaces. Accordingly, the main contributions of this study are as follows:

(1) By combining questionnaire surveys with field observations, this study derives modular wardrobe design requirement criteria across the dimensions of spatial storage, dynamic adaptability, structural performance, and sensory aesthetics. This process transforms complex clothing storage problems in compact living spaces into specific and quantifiable evaluation criteria.

(2) IPA is introduced to screen and classify user requirement attributes, and the CRITIC weighting method is integrated to determine the priority of design requirements.

(3) Taking modular wardrobe design for compact living spaces as an example, this study translates the weight-ranking results into concrete design alternatives. TOPSIS is then applied to conduct multi-criteria evaluation and evidence-based selection, thereby establishing an optimal design scheme.

LITERATURE REVIEW

Current Research on Modular Furniture Design

With the acceleration of global urbanization and the widespread adoption of high-density living environments, improving the residential experience within limited spaces has become a critical issue. Because of its functional flexibility, high spatial adaptability, and potential for standardized production, modular furniture has attracted increasing attention in the field of furniture design. From a product life-cycle perspective, Wang (2022) proposed a modular cabinet design aimed at improving the sustainable utilization of furniture. As research on sustainable materials has advanced, Cervera *et al.* (2024) and Lo *et al.* (2025) investigated how cultivated microalgae-based materials and natural bamboo materials, respectively, can be applied to modular furniture to enable carbon dioxide capture and enhance circular economy performance, thereby promoting environmental sustainability.

On the production side of modular furniture, Siemiatkowski and Vargovská (2019) and Kantaros *et al.* (2025) optimized the manufacturing layout of modular customized furniture and the fabrication methods for modular furniture from systems-engineering and technical perspectives, respectively. These efforts improved the efficiency of the overall production system and reduced material waste. With the rapid development of the Internet of Things and intelligent sensing technologies, the research scope of modular furniture has begun to expand toward structural transformation and smart interaction (Zhang *et al.* 2024). One study developed a foldable modular chain structure that enables furniture to achieve shape transformation. Meanwhile, the integration of smart hardware has transformed modular furniture from a static carrier into an active interactive terminal. For example, (Gómez-Carmona *et al.* 2019) and (Rakauskas *et al.* 2025) integrated intelligent interaction systems and multimodal sensing systems into modular smart urban furniture and modular smart seating, respectively, enabling these products to respond to users' needs in different contexts in real time. With the development of advanced manufacturing technologies and the iterative evolution of product functions, accurately identifying users' genuine requirements from a wide range of design needs has encouraged research on quantifying user requirements. Accordingly, innovative multi-criteria decision-making methods have emerged to support the scientific evaluation of furniture design (Zhao and Xu 2023). One study used an evaluation model integrating the Kano model, AHP, and Grey relational analysis to reveal evaluation preferences for modular children's storage cabinets (Miao *et al.* 2026). Another study combined the Kano model with the inventive principles of TRIZ to develop a customizable modular smart workspace design that better satisfies users' preference for highly practical products (Kuys *et al.* 2021). A human-centered design (HCD) approach has also been used to demonstrate how research data can be translated into final product concepts. Overall, these studies, ranging from product sustainability and material research to the intelligent development of modular furniture and the construction of quantitative design models, collectively establish a multidimensional innovation system for modular furniture.

However, existing studies still have several notable limitations. There remains a lack of systematic investigation into the requirements for core household storage furniture that is frequently used in daily life. In addition, current research has focused primarily on material development and sustainability strategies for modular furniture, while paying insufficient attention to product-use requirements from the user perspective. This limits the potential to improve user satisfaction with modular furniture in actual use.

To overcome these limitations, this study focused on modular wardrobe design for compact living spaces. User interviews and questionnaire surveys were conducted to explore users' pain points and requirements regarding the use of modular furniture in depth. In addition, the IPA model was introduced to accurately identify users' perceived satisfaction with and importance of wardrobe design attributes, thereby determining the key design criteria requiring improvement and ensuring a comprehensive and precise capture of user requirements.

Application of Multi-criteria Decision-making Methods in Furniture Design

In recent years, with the rapid development of digital technologies and the full emergence of mass customization, the paradigm of furniture design has gradually shifted from designer-experience-driven practice to user-requirement-driven design. Alongside the maturation of data collection and analysis technologies, multi-criteria decision-making (MCDM) methods have become a key mechanism for translating abstract personalized requirements into precise product parameters. In a data-driven context, Zhao and Xu (2023) incorporated the gradient boosting decision tree (GBDT) model into a conventional AHP evaluation framework and used fuzzy comprehensive evaluation (FCE) to support prototype assessment and optimization. This approach substantially improved the predictive accuracy of sustainability evaluation for recycled plastic furniture. However, reliance solely on computational algorithms is insufficient to fully capture the complexity of users' psychological responses.

To improve the interpretability of design decision-making, research has gradually extended toward the precise translation of user requirements and the analysis of causal logic. Within this trend, Chang *et al.* (2025) adopted the fuzzy Kano (FKANO) model to accurately filter user requirements for urban public seating and used the DEMATEL method to examine the potential causal relationships among design criteria in depth. This approach provided a logical basis for subsequent optimization using the TOPSIS method. As the degree of product customization continues to increase, the factors embedded in furniture design criteria have become increasingly complex. To balance functionality, aesthetics, and manufacturability, integrated subjective-objective weighting and multi-objective decision-making have emerged as effective solutions.

The limitations of single-weighting approaches prompted Ren and Qu (2024) to develop an integrated model combining the FKANO, CRITIC, and CCD methods, which significantly improved the objectivity of the decision-making process (Yao *et al.* 2026). Additional studies further integrated statistical methods, including PCA, ORA, and CRITIC, to combine subjective and objective criterion weights, and subsequently applied TOPSIS to identify the optimal design scheme. Overall, the continuous integration of algorithms and decision-making models has greatly expanded the boundaries of scientific evaluation in furniture design.

Although the iterative development of the above multi-criteria decision-making methods has provided innovative data-driven strategies for responding to market changes, limitations remain in specific and complex design contexts. The most prominent limitation

is that existing requirement identification frameworks tend to emphasize user preferences, but lack an intuitive means of quantifying the dynamic gap between users' perceived importance and the actual performance of current products. As a result, subsequent design optimization lacks precise prioritization. In addition, previous studies have mostly adopted integrated weighting methods to calculate the weights of product design criteria, but have not fully explored or objectively quantified the inherent conflict intensity among design criteria.

To address these challenges, this study proposes an integrated IPA-CRITIC-TOPSIS multi-criteria decision-making optimization method for modular wardrobe design. The IPA model is first used to directly identify core design pain points characterized by high importance but low satisfaction, thereby establishing an optimization direction guided by users' perceived gaps. The CRITIC method is then applied to quantify the conflict intensity among criteria based on data variability and intercriteria correlations. By quantifying the degree of conflict among criteria based on data variability and correlation structure, this approach reduced the subjectivity associated with expert-based weighting. Finally, TOPSIS is used to select the optimal design alternative. This integrated quantitative pathway establishes a data-driven optimization method based on user requirements for customized furniture design in space-constrained living environments. It also provides an efficient and scientific reference framework for overcoming the limitations of traditional experience-based design and single-objective decision-making approaches.

METHODOLOGY

Proposed Framework

This study proposes a hybrid multi-criteria decision-making framework that integrates IPA, CRITIC, and TOPSIS. The framework identifies users' core requirements, quantify criterion weights, and comprehensively evaluate and select the optimal alternative among multiple modular wardrobe design schemes. In doing so, it reduces subjective bias in traditional design decision-making and provides a quantitative approach for evaluating and comparing alternatives in the development of customized modular furniture. Figure 1 illustrates the proposed framework, and the specific research steps are as follows:

Acquisition and screening of user requirements. Key factors influencing the user experience of modular wardrobes were collected through semi-structured user interviews. An IPA questionnaire was then designed, with all items rated on a five-point Likert scale. After the questionnaire data was collected, an IPA quadrant matrix was constructed to screen and identify the improvement criteria located in the high-importance, low-satisfaction quadrant. These criteria were defined as the key requirement elements for subsequent optimization, and a criterion system was established according to their priority levels.

Calculation of conflict-based criterion weights. For the screened key design criteria, an evaluation matrix was established and the CRITIC method was introduced. The standard deviation of the criterion data was used to measure the degree of variability, while correlation coefficients among criteria were calculated to assess intercriteria conflict. The contrast intensity and conflict degree of each criterion were then integrated and normalized to obtain information-based weights.

Modular wardrobe design alternatives. Based on the core requirements screened using the IPA method and the information-based weights calculated using the CRITIC method, three modular wardrobe design alternatives were proposed for compact living spaces.

Comprehensive evaluation and selection of alternatives using TOPSIS. A decision matrix was constructed based on the three modular wardrobe design alternatives. The TOPSIS method was then applied to calculate the distance of each alternative from the positive and negative ideal solutions, thereby deriving the relative closeness coefficient of each alternative. Finally, the optimal design alternative was determined according to the ranking results, providing a quantitative basis for decision-making in modular wardrobe design.

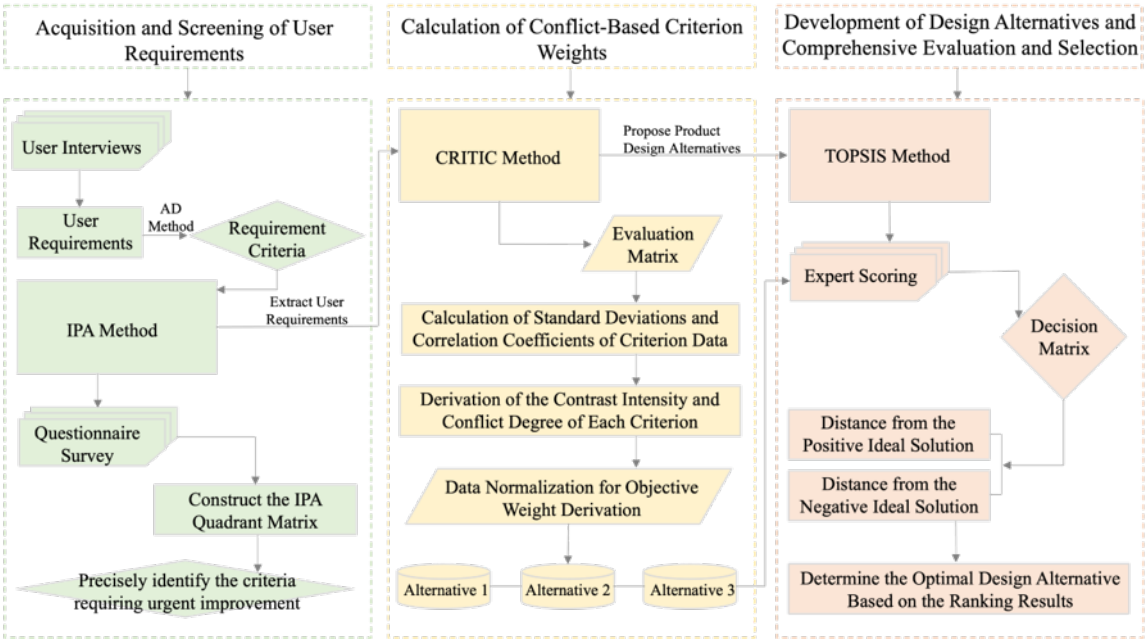


Fig. 1. Research framework

Affinity Diagram Method

AD, developed by the Japanese anthropologist Jiro Kawakita, is an analytical tool used to systematically classify dispersed and unstructured qualitative data according to inherent similarities. The core of this method is to record collected ideas, observations, problems, or user data statements on separate cards, and then group them based on intrinsic associations and similarities within the information. This process helps construct a clear hierarchical structure (Qin *et al.* 2025).

In this study, AD was used to organize and synthesize user requirements for modular wardrobes. The specific implementation steps were as follows:

(1) The research team extracted original statements collected through preliminary semi-structured interviews on urban residents' daily storage habits and pain points when using conventional wardrobes. Statements with an occurrence frequency of at least three were selected and converted into individual text cards. Statements unrelated to wardrobe functions or entirely deviating from the wardrobe product context were classified as invalid requirements and removed after approval by more than half of the research team.

(2) The cards were then merged and reorganized by a focus group according to semantic similarity, relevance, or logical relationships. After the initial merging and reorganization, a focus group discussion was held to remove semantic redundancies among statements that differed in wording but shared the same core meaning. A second round of discussion was then conducted, using bottom-up inductive logic to cluster and merge similar conceptual labels.

(3) When disagreement arose within the focus group regarding the classification of a given criterion, multiple rounds of discussion were conducted until consensus was reached.

IPA Method

The IPA method was first proposed by Martilla and James in 1977. It aims to identify the gap between consumers' perceived importance and satisfaction by measuring the importance and performance of product attributes, thereby providing designers with strategic guidance for improving products or services (Sun *et al.* 2023). In this study, IPA was used to analyze users' evaluations of the importance and satisfaction of each modular wardrobe design criterion. Its purpose was to accurately identify actual storage pain points and core design requirements. The specific implementation steps were as follows:

(1) Construction of the evaluation criterion system. Based on the preliminary semi-structured interviews, users' functional requirements when using conventional or modular wardrobes were classified and refined through AD. This process enabled the initial construction of an evaluation criterion system for modular wardrobe design.

(2) Determination and quantification of evaluation data. An IPA questionnaire was developed based on the above criteria. Respondents were asked to rate the importance (*I*) and satisfaction (*P*) of each criterion separately using a five-point Likert scale. The scores ranged from 1 to 5, corresponding to very unimportant or very dissatisfied, unimportant or dissatisfied, neutral, important or satisfied, and very important or very satisfied, respectively. After valid questionnaire data were collected, the mean importance score $\overline{I}_j$ and mean satisfaction score $\overline{P}_j$ for each criterion were calculated as follows,

$$\overline{I}_j = \frac{1}{N}\sum_{s=1}^{N} I_{sj} \tag{1}$$

$$\overline{P}_j = \frac{1}{N}\sum_{s=1}^{N} P_{sj} \tag{2}$$

where (*N*) denotes the total number of valid respondents participating in the evaluation.

(3) To determine the central coordinates of the analysis matrix, this study used the overall mean importance score of all evaluation criteria as the vertical division threshold and the overall mean satisfaction score as the horizontal division threshold. The calculation formulas are as follows,

$$\overline{I}_{total} = \frac{\sum_{j=1}^{n}\overline{I}_j}{n} \tag{3}$$

$$\overline{P}_{total} = \frac{\sum_{j=1}^{n}\overline{P}_j}{n} \tag{4}$$

where (n) denotes the total number of evaluation criteria for modular wardrobe design.

(4) Drawing the IPA quadrant diagram and screening the requirements. In the IPA framework of this study, satisfaction was set as the horizontal axis, namely, the X-axis, and importance was set as the vertical axis, namely, the Y-axis. The matrix was then divided into four quadrants, as shown in Fig. 2. Using the overall mean satisfaction score $\bar{P}$ and the overall mean importance score $\bar{I}$ as the central division point, the coordinates of each criterion, (P_j, I_j), were mapped onto a two-dimensional coordinate space.

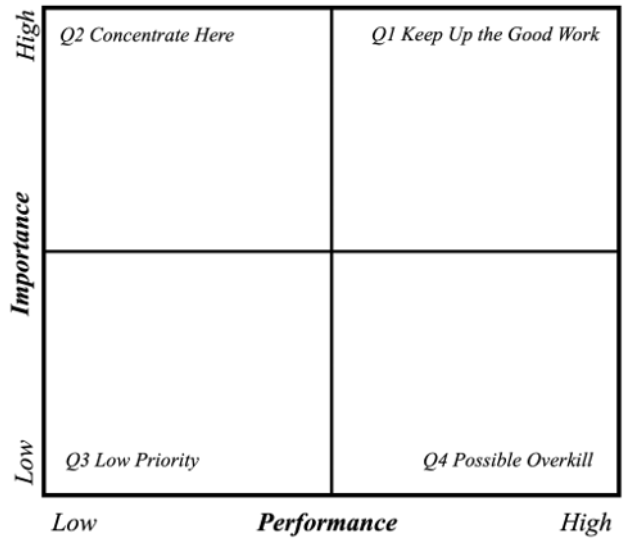


Fig. 2. Four IPA quadrants

Quadrant I, Keep up the Good Work: high importance and high satisfaction.

Quadrant II, Concentrate Here: high importance but low satisfaction. The criteria in this quadrant represent users' most critical pain points.

Quadrant III, Low Priority: low importance and low satisfaction.

Quadrant IV, Possible Overkill: low importance but high satisfaction.

CRITIC Method

The CRITIC method, proposed by Diakoulaki, derives information-based weights from score dispersion and intercriterion correlations. These weights primarily reflect the information content of each criterion and its degree of conflict with the other criteria (Yao *et al.* 2026). In this study, The CRITIC method was used to derive weights from the importance ratings provided by 128 users for the core requirement criteria identified through IPA. The resulting weights are referred to as CRITIC information-based weights. Although this method reduces reliance on weights assigned directly by experts, it should not be regarded as a fully objective weighting procedure independent of subjective judgment. The specific calculation steps were as follows:

(1) Data normalization. First, the constructed raw evaluation matrix was normalized to eliminate the influence of different measurement scales across dimensions. The normalization formula is as follows:

For benefit criteria, where larger values indicate better performance:

$$x'_{sj} = \frac{x_{sj} - \min(x_j)}{\max(x_j) - \min(x_j)} \tag{5}$$

For cost criteria, where smaller values indicate better performance:

$$x'_{sj} = \frac{\max(x_j) - x_{sj}}{\max(x_j) - \min(x_j)} \tag{6}$$

where x_{sj} denotes the original score of the s-th sample on the j-th criterion, and x'_{sj} represents the normalized value; $\max(x_j)$ and $\min(x_j)$ denote the maximum and minimum values of the j-th criterion, respectively.

(2) Calculation of the standard deviation of each criterion. The standard deviation reflects the degree of variation in user evaluations for the same design criterion and is commonly denoted by σ_j:

$$\sigma_j = \sqrt{\frac{1}{p}\sum_{s=1}^{p}\left(x'_{sj} - \overline{x}'_j\right)^2} \tag{7}$$

A larger standard deviation σ_j indicates greater variation in users' evaluations of the corresponding design criterion, suggesting that the criterion contains richer useful information. Here, $\overline{x}'_j$ denotes the mean value of the j-th criterion, and (p) represents the number of samples.

(3) Calculation of correlation coefficients among criteria. The correlation coefficient r_{jk} between criterion j and criterion k was calculated as follows:

$$r_{jk} = \frac{\sum_{s=1}^{p}\left(x'_{sj} - \overline{x}'_j\right)\left(x'_{sk} - \overline{x}'_k\right)}{\sqrt{\sum_{s=1}^{p}\left(x'_{sj} - \overline{x}'_j\right)^2 \sum_{s=1}^{p}\left(x'_{sk} - \overline{x}'_k\right)^2}} \tag{8}$$

(4) Calculation of the conflict degree and information content of each criterion. The correlation coefficient matrix was used to measure the conflict degree among criteria (R_j), where (q) denotes the total number of criteria:

$$R_j = \sum_{k=1}^{q}\left(1 - r_{jk}\right) \tag{9}$$

The comprehensive information content contained in criterion j, denoted as Cj, is calculated as follows:

$$C_j = \sigma_j \cdot R_j \tag{10}$$

If a criterion has a lower correlation with other criteria, namely a smaller r_{jk}, it indicates less overlapping information and a stronger conflict degree with the other criteria. This suggests that the criterion contains more independent information for design evaluation.

(5) Determination of final weights. Finally, the final information-based weight w_j was calculated based on the information content Cj of each criterion:

$$w_j = \frac{C_j}{\sum_{j=1}^{q} C_j} \tag{11}$$

The sum of the weights of all criteria equals 1, namely $\sum_{j=1}^{q} w_j = 1$.

In summary, when the standard deviation remains constant, a smaller correlation coefficient between a given design criterion and the other criteria indicates a greater conflict degree among criteria, resulting in a larger assigned weight. When the correlation coefficient remains fixed, a larger standard deviation indicates stronger criterion variability and therefore a larger weight. Accordingly, a higher CRITIC weight indicates that a design criterion exhibits greater variability and a higher degree of conflict with other criteria within the current rating matrix.

TOPSIS Method

TOPSIS is a comprehensive evaluation method that is widely used in multi-criteria decision-making (MCDM). Its basic principle is that the optimal alternative should be as close as possible to the positive ideal solution and as far as possible from the negative ideal solution (Zhang *et al.* 2024). In this study, to objectively validate the design outcomes across multiple dimensions, TOPSIS was applied for the final evaluation and selection of multiple modular wardrobe design alternatives based on the information-based criterion weights obtained using the CRITIC method. The specific implementation steps were as follows,

(1) Construction of the initial decision matrix. Suppose that *a* modular wardrobe design alternatives are developed in this study and evaluated according to *b* core evaluation criteria. Accordingly, the initial decision matrix *X* is constructed as follows,

$$X = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1b} \\ x_{21} & x_{22} & \cdots & x_{2b} \\ \vdots & \vdots & \ddots & \vdots \\ x_{a1} & x_{a2} & \cdots & x_{ab} \end{bmatrix} \tag{12}$$

where x_{ij} denotes the performance score of the *i*-th modular wardrobe design alternative under the *j*-th evaluation criterion, with (i = 1, 2, ..., a; j = 1, 2, ..., b).

(2) Normalization of the decision matrix: To eliminate the influence of differences in dimensions, units, or evaluation scales among the evaluation criteria, the initial decision matrix was vector-normalized to obtain the normalized decision matrix $Z = [z_{ij}]_{a\times b}$,

$$z_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{a} x_{ij}^2}} \tag{13}$$

where x_{ij} denotes the element of the normalized matrix.

(3) Construction of the weighted normalized decision matrix: The comprehensive information-based weight w_j of each requirement criterion, calculated previously using the CRITIC method, was combined with the normalized matrix to obtain the weighted normalized decision matrix $V = [v_{ij}]_{a\times b}$:

$$v_{ij} = w_j \cdot z_{ij} \tag{14}$$

(*4) Determination of the positive and negative ideal solutions.* In the weighted normalized decision matrix, the optimal and worst values under each evaluation criterion

were identified to form the positive ideal solution V^+ and the negative ideal solution V^-, respectively,

$$V^+ = (v_1^+, v_2^+, \ldots, v_b^+), \qquad v_j^+ = \max_i(v_{ij}) \tag{15}$$

$$V^- = (v_1^-, v_2^-, \ldots, v_b^-), \qquad v_j^- = \min_i(v_{ij}) \tag{16}$$

where V^+ represents the set of maximum values of all alternatives under each criterion, corresponding to the most desirable state, while V^- represents the set of minimum values, corresponding to the least desirable state.

(5) Calculation of Euclidean distances. The Euclidean distance of each modular wardrobe design alternative from the positive ideal solution, denoted as D_i^+, and from the negative ideal solution, denoted as D_i^-, was calculated. The formulas are as follows:

$$D_i^+ = \sqrt{\sum_{j=1}^{b}\left(v_{ij} - v_j^+\right)^2} \tag{17}$$

$$D_i^- = \sqrt{\sum_{j=1}^{b}\left(v_{ij} - v_j^-\right)^2} \tag{18}$$

(6) Calculation of relative closeness. To comprehensively evaluate the performance of each design alternative, the relative closeness coefficient C_i of each alternative to the ideal solution was calculated:

$$C_i = \frac{D_i^-}{D_i^+ + D_i^-} \tag{19}$$

where C_i ranges from 0 to 1. A larger C_i value, closer to 1, indicates that the design alternative is closer to the positive ideal solution and farther from the negative ideal solution. This suggests better overall performance of the design alternative, whereas a smaller value indicates poorer performance.

CASE STUDY

Acquisition and Screening of User Requirements

Prior to participation, all interviewees, survey respondents, and evaluators of the design alternatives were informed of the study purpose, research procedures, voluntary nature of participation, confidentiality safeguards, and intended academic use of the data. Participants were informed that they could withdraw from the study at any time without penalty or adverse consequences. Written or electronic informed consent was obtained from all participants before data collection.

As the core storage system in compact living spaces, modular wardrobes must be optimized based on the actual requirements of target users. To examine storage behaviors in real-world use contexts, this study conducted field observations and semi-structured interviews with target users. A total of 12 urban residents were recruited, including 5 men

and 7 women aged 22 to 45 years. All participants lived in high-density housing and were responsible for the daily storage and management of household clothing.

The interview questions focused primarily on daily storage habits, pain points related to seasonal clothing storage, dissatisfaction with the spatial layout of conventional fixed wardrobes, and expectations regarding modular adjustment functions. To ensure technical rigor, four product designers with more than five years of experience in furniture design were additionally invited to provide professional insights into manufacturing requirements, including structural design and durability. The interview outline is provided in Appendix A.

A large number of raw requirement statements were collected through these procedures. To eliminate semantic redundancy and ensure criterion independence and completeness, this study organized an eight-member focus group, consisting of three professors in product design, two furniture designers, and three consumer representatives. A total of 165 raw statements were obtained, from which 138 requirement cards were extracted and 27 invalid statements were removed. After two rounds of clustering, 18 core design requirement criteria were generated, as shown in Fig. 3. The specific design requirements and their contents are presented in Table 1.



Fig. 3. Affinity diagram

Based on the design requirement criteria identified above, this study employed a five-point Likert scale to measure the importance target users assigned to each requirement and their satisfaction with how well their current wardrobes met that requirement. Because satisfaction was rated on the basis of respondents' previous or current wardrobe-use experiences, the resulting scores represent perceived performance across diverse real-world usage contexts.

A total of 136 questionnaires were collected, of which 128 were judged as valid. The valid respondents included 57 men and 71 women. Their residential characteristics included 63 young white-collar workers living in small apartments, 36 renters with frequent relocation experience, and 29 users with recent partial home-renovation needs. To ensure the relevance and diversity of the questionnaire data, the survey was distributed through a combination of online and offline channels.

Table 1. Design Requirements and Descriptions

Code	Design Requirement	Requirement Description
A1	Internal Functional Zoning	Proportion and layout of areas for hanging long and short garments, folded clothing, and drawer storage.
A2	Corner-Space Utilization	Effective use of blind spots, including the top, bottom, and corner areas of the wardrobe.
A3	Adjustability of Storage Accessories	Flexible customization of shelf height, hanging rod position, and storage depth.
A4	Ease of Clothing Access and Retrieval	Extent of unobstructed access to clothing within the optimal visual and reach zone.
A5	Storage of Special Items	Storage support for items such as extra-long skirts, large suitcases, and thick seasonal bedding.
A6	Deformation Resistance of Modular Connections	Tightness and stability of connectors after repeated assembly and disassembly.
A7	Structural Safety Mechanisms	Anti-tip design, damping buffers, and finger-pinch protection to prevent accidental injury.
A8	Hardware Durability	Noise performance and long-term service life of frequently used components, such as slides and hinges.
A9	Environmental Performance of Panel Materials	Formaldehyde emission level of the material.
A10	Wardrobe Sealing Performance	Door-panel fit and protection against humid environments, such as rainy-season conditions.
A11	Aesthetic Appearance	Versatility of the form design and its compatibility with modern interior decoration styles.
A12	Material Tactility	Surface finish quality, scratch resistance, and fingerprint resistance of the panels.
A13	Color and Form	Use of low-saturation colors and forms to visually reduce spatial heaviness.
A14	Auxiliary Lighting	Built-in motion-sensor lighting.
A15	Component Assembly and Disassembly	Ease of component assembly and disassembly.
A16	Part Replacement and Capacity Expansion	Compatibility with standardized accessories and subsequent capacity expansion.
A17	Damage-Free Assembly and Disassembly	Resistance to damage during disassembly and reassembly for relocation or room-function changes.
A18	Daily Cleaning and Maintenance	Ease of cleaning internal surfaces.

Statistical analysis of the questionnaire data showed that the mean importance scores $\overline{I}_j$ of the 18 wardrobe design criteria ranged from 3.45 to 4.60, while the mean satisfaction scores $\overline{P}_j$ ranged from 2.68 to 4.12. The mean importance and satisfaction scores for each design criterion are presented in Table 2. The overall mean satisfaction score was 3.42, and the overall mean importance score was 4.16. Therefore, the center point of the IPA coordinate system was determined as (3.42, 4.16). The four-quadrant scatter plot constructed based on this center point reflects users' perceived importance and satisfaction for each design criterion, as shown in Fig. 4.

Quadrant I represents criteria with high importance and high satisfaction. This quadrant includes design criteria A7, A8, A9, A11, and A12, indicating that these attributes

should be strictly maintained as baseline standards to ensure the fundamental market competitiveness of the product.

Quadrant II represents criteria with high importance but low satisfaction. This quadrant includes design criteria A1, A2, A3, A4, A5, A10, and A17, indicating that these criteria constitute the most critical user pain points in this study and serve as the core driving factors for optimizing modular wardrobe design.

Quadrant III represents criteria with low importance and low satisfaction. This quadrant includes design criteria A6, A14, A15, and A16, suggesting that these criteria are not key factors influencing users' primary decision-making.

Quadrant IV represents criteria with low importance but high satisfaction. This quadrant includes design criteria A13 and A18, indicating that excessive cost investment in these attributes should be avoided.

Table 2. Priority Ranking of Design Requirements

Code	Design Requirement	Mean Importance Score *I*	Mean Satisfaction Score *P*	Priority
A1	Internal Functional Zoning	4.35	3.15	Concentrate Here
A2	Corner-Space Utilization	4.50	2.85	Concentrate Here
A3	Adjustability of Storage Accessories	4.38	2.92	Concentrate Here
A4	Ease of Clothing Access and Retrieval	4.45	3.24	Concentrate Here
A5	Storage of Special Items	4.22	3.05	Concentrate Here
A6	Deformation Resistance of Modular Connections	3.95	3.38	Low Priority
A7	Structural Safety Mechanisms	4.35	3.85	Keep up the Good Work
A8	Hardware Durability	4.45	3.78	Keep up the Good Work
A9	Environmental Performance of Panel Materials	4.60	4.12	Keep up the Good Work
A10	Wardrobe Sealing Performance	4.35	3.35	Concentrate Here
A11	Aesthetic Appearance	4.25	3.90	Keep up the Good Work
A12	Material Tactility	4.18	3.75	Keep up the Good Work
A13	Color and Form	3.88	3.82	Possible Overkill
A14	Auxiliary Lighting	3.65	3.20	Low Priority
A15	Component Assembly and Disassembly	3.45	3.10	Low Priority
A16	Part Replacement and Capacity Expansion	3.85	3.32	Low Priority
A17	Damage-Free Assembly and Disassembly	4.32	2.68	Concentrate Here
A18	Daily Cleaning and Maintenance	3.75	4.05	Possible Overkill

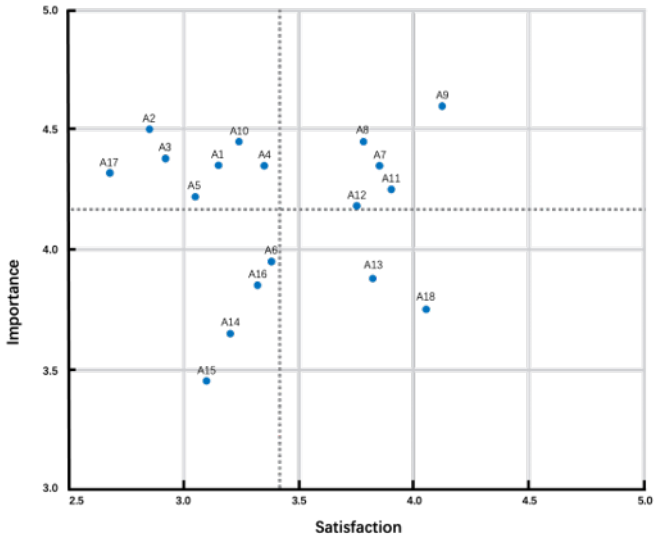


Fig. 4. Importance-performance analysis (IPA) quadrant plot of design criteria

Table 3. Correspondence Between the Original IPA Codes and the Codes in the Evaluation Criteria System

Original Code	Design Requirement	Criterion Code	Processing Outcome	Original Code	Design Requirement	Criterion Code	Processing Outcome
A1	Internal Functional Zoning	S11	Retained	A10	Wardrobe Sealing Performance	P13	Retained
A2	Corner-Space Utilization	S12	Retained	A11	Aesthetic Appearance	E11	Retained
A3	Adjustability of Storage Accessories	M11	Retained	A12	Material Tactility	E12	Retained
A4	Ease of Clothing Access and Retrieval	S13	Retained	A13	Color and Form	—	Excluded
A5	Storage of Special Items	S14	Retained	A14	Auxiliary Lighting	—	Excluded
A6	Deformation Resistance of Modular Connections	—	Excluded	A15	Component Assembly and Disassembly	—	Excluded
A7	Structural Safety Mechanisms	P11	Retained	A16	Part Replacement and Capacity Expansion	—	Excluded
A8	Hardware Durability	P12	Retained	A17	Damage-Free Assembly and Disassembly	M12	Retained
A9	Environmental Performance of Panel Materials	P14	Retained	A18	Daily Cleaning and Maintenance	—	Excluded

To achieve the optimal configuration of design criteria while avoiding data interference from low-priority requirements in the subsequent evaluation model, this study performed dimensionality reduction based on the IPA results. Specifically, five baseline constraints from Quadrant I and seven core innovation criteria from Quadrant II were extracted. Ultimately, the selected requirements were grouped according to their attributes into four primary design criteria: S1, spatial storage functionality; M1, dynamic modular adaptability; P1, structural safety performance; and E1, sensory and aesthetic experience. The code mappings following the screening process are presented in Table 3, and the resulting evaluation criteria system for modular wardrobe design is shown in Fig. 5.

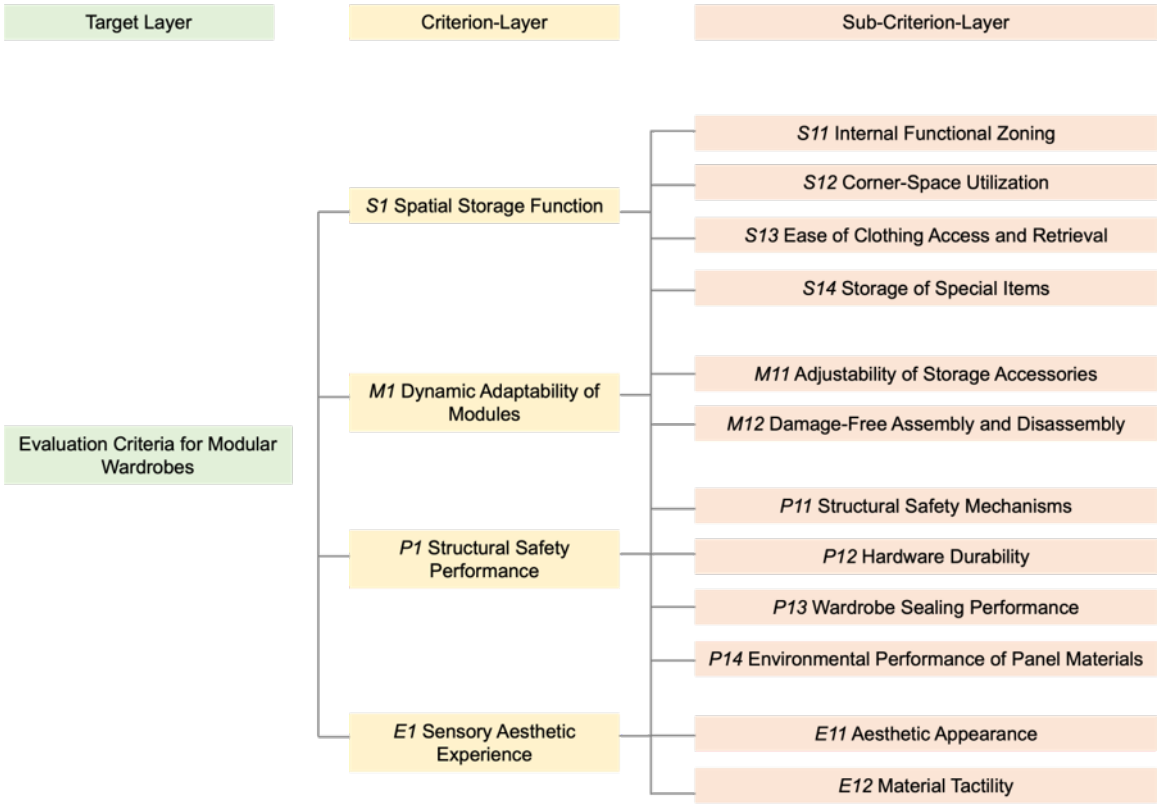


Fig. 5. Evaluation criteria for modular wardrobe design

Table 4. Scoring Matrix of 12 Design Criteria by 128 Users

Criterion	*S11*	*S12*	*S13*	*S14*	*M11*	*M12*	*P11*	*P12*	*P13*	*P14*	*E11*	*E12*
User1	5	3	4	5	4	5	4	4	4	5	4	4
User2	4	5	5	4	5	3	4	4	4	4	5	4
User3	5	5	4	4	5	4	4	5	5	5	4	4
User4	5	4	5	4	4	5	5	5	4	5	4	4
User5	4	5	5	4	5	4	4	5	4	4	3	4
User6	4	5	4	4	4	5	5	4	4	5	4	5
…	…	…	…	…	…	…	…	…	…	…	…	…
User126	4	4	5	4	5	5	4	4	4	5	4	4
User127	4	3	4	4	4	3	5	4	5	5	5	4
User128	4	5	4	4	5	5	4	4	4	5	4	4

Calculation of Conflict-based Criterion Weights

To quantify the priority of each design requirement in the overall design optimization process, this study employed the CRITIC method to derive information-based weights for the criteria. The raw importance-rating data provided by 128 users for the 12 high-priority design criteria in the preceding IPA questionnaire survey were extracted to construct the initial matrix, as shown in Table 4.

The raw quantitative data from the 128 users were first normalized. The standard deviation σ_j and conflict degree R_j of each design criterion were then calculated, thereby deriving the information content C_j and information-based weight w_j of each criterion. The specific calculation results are shown in Table 5.

Table 5. Information-based Weight Ranking of the Design Criterion System

Primary Criterion	Secondary Criterion	Standard Deviation (σ_j)	Conflict Degree (R_j)	Information Content (C_j)	Information-based Weight (w_j)	Rank-ing
S1 Spatial Storage Function	S11 Internal Functional Zoning	0.495	9.097	4.507	0.0933	3
	S12 Corner-Space Utilization	0.517	9.420	4.874	0.1009	2
	S13 Ease of Clothing Access and Retrieval	0.514	8.418	4.331	0.0896	5
	S14 Storage of Special Items	0.451	8.506	3.839	0.0795	7
M1 Dynamic Adaptability of Modules	M11 Adjustability of Storage Accessories	0.517	8.638	4.469	0.0925	4
	M12 Damage-Free Assembly and Disassembly	0.516	9.855	5.089	0.1053	1
P1 Structural Safety Performance	P11 Structural Safety Mechanisms	0.495	7.518	3.725	0.0771	8
	P12 Hardware Durability	0.514	7.101	3.654	0.0756	9
	P13 Wardrobe Sealing Performance	0.495	8.174	4.050	0.0838	6
	P14 Environmental Performance of Panel Materials	0.507	6.166	3.128	0.0647	11
E1 Sensory Aesthetic Experience	E11 Aesthetic Appearance	0.452	7.811	3.534	0.0731	10
	E12 Material Tactility	0.385	8.098	3.121	0.0646	12

Modular Wardrobe Design Alternatives

Based on the comprehensive weight ranking of the design criteria, three design alternatives were developed for compact living spaces. Each alternative prioritized the top five ranked design criteria, namely M12 damage-free assembly and disassembly, S12 corner-space utilization, S11 internal functional zoning, M11 adjustability of storage accessories, and S13 ease of clothing access and retrieval.

All three design alternatives were developed based on the same modular system and specified wood-based composite materials that meet the E0 environmental standard for formaldehyde emissions (≤ 0.050 mg/m³). The wardrobe body followed the

internationally adopted 32 mm system for panel furniture, with a uniform depth of 600 mm to accommodate standard clothes hangers. The cabinet side panels were designed with predrilled holes measuring 5 mm in diameter and spaced 32 mm center to center. These holes provide predefined mounting positions for cabinet connectors, shelf supports, hinge mounting plates, drawer slides, and embedded metal channel rails, allowing installation and reassembly without further drilling into the wood-based panels. Each of the three wardrobes measured 2400 mm in length and 2400 mm in height. The overall wardrobe system consisted of two parts: a static outer-frame unit and dynamic functional components, namely, the load-bearing frame and components such as shelves, drawers, hanging rods, and pull-out baskets. High-strength metal slot rails were embedded at different heights in the side panels of the wardrobe, and all dynamic functional components were equipped with self-locking movable clips. Users need only hang the components on the rails, after which they automatically lock into place. All three alternatives support customized adjustment, allowing users to freely increase or decrease the number of shelves, add drawers, or adjust component heights according to their needs, thereby enabling the subdivision and reconfiguration of storage space. In addition, to save corridor space and meet dust-proof and moisture-proof requirements, the wardrobe uses coplanar sliding doors. When opened, the door panels move outward in parallel, are slightly offset from the cabinet front, and slide sideways. When closed, the two door panels automatically return to the same plane.

Alternative 1: Comprehensive storage-oriented modular wardrobe. This alternative adopts a large-scale spatial partitioning strategy, with hanging and folding areas designed to maximize storage capacity. It incorporates relatively few movable components, with functional conversion achieved primarily by interchanging shelves and hanging rods. Consequently, its assembly and disassembly process is relatively straightforward. A 1200-mm-long-garment hanging space is reserved on the right side, while three large hanging areas are arranged on the left side.



Fig. 6. Design alternative 1

The middle section contains folding and storage compartments of different sizes to accommodate items with varying dimensions. Drawers for storing underwear and small garments are placed at the bottom. When more long-garment storage is needed in autumn and winter, users can remove the shelves and replace them with hanging rods. In spring

and summer, additional shelves can be installed to convert the space into a folding area for T-shirts and trousers. Drawers can also be added to the middle section of the wardrobe according to users' needs, thereby increasing the overall storage capacity. This alternative is characterized primarily by large storage zones and fixed hanging-storage areas, with relatively few pull-out components, as shown in Fig. 6.

Alternative 2: Space-efficiency-oriented modular wardrobe. This alternative adopts a high-density grid-based spatial planning strategy and incorporates numerous mounting interfaces for shelves and drawers. In addition to retaining the necessary core hanging area, multiple folding compartments of different sizes are arranged on the left side and in the middle-lower section, while flexible space is reserved at the bottom to accommodate large suitcases. Users can add shelves and drawers as needed, thereby forming dedicated folding areas for garments such as sweaters and jeans. The high-density grid-based arrangement effectively avoids the wasted space commonly caused by excessive shelf spacing in conventional wardrobes, while further improving space utilization and storage functionality, as shown in Fig. 7.



Fig. 7. Design alternative 2

Alternative 3: Refined zoning-oriented modular wardrobe. While retaining the core distinction between long- and short-garment areas, this alternative introduces pull-out storage modules. Multiple drawers and stainless steel pull-out baskets are densely arranged within the optimal viewing and reach zone. Consequently, this alternative contains the greatest number of movable components and connection interfaces. This refined zoning strategy provides convenient storage and retrieval space specifically for small garments, such as underwear and socks. A transparent glass display tray is positioned in the central section of the wardrobe to provide visible storage for accessories such as scarves, ties, sunglasses, and watches, with the aim of improving users' search efficiency in high-frequency routines such as morning commuting. Users can adjust the tray height, add drawers and shelves, and further subdivide the storage functions according to their needs, as shown in Fig. 8.



Fig. 8. Design alternative 3

Comprehensive Evaluation and Selection of Alternatives Using TOPSIS

To compare and select among the three developed modular wardrobe design alternatives scientifically and objectively, this study introduced the TOPSIS method for design evaluation. At this stage, the CRITIC information-based weights obtained in the preceding section were incorporated to quantitatively evaluate and rank the overall performance of each alternative. A stratified sampling strategy was adopted to recruit 10 participants to form an evaluation decision-making panel, which included three furniture design experts and seven target users. The furniture design experts had at least five years of professional experience in customized furniture design, ensuring that concept-level manufacturability was assessed by appropriately qualified evaluators. The target users currently lived in small or compact apartments and had at least one rental relocation experience or experience leading a whole-house customized furniture project. This ensured that they had practical awareness of product-use pain points and were able to independently understand the 12 secondary evaluation criteria.

To improve the consistency and objectivity of the scoring process, all evaluators received the same product evaluation dossier before assessment. The dossier included design drawings of the three alternatives, diagrams of their internal functional zoning and configurations, key dimensional information, details of the modular structures, and a description of each alternative. A detailed engineering specification sheet was also provided, clearly identifying the hardware connection mechanisms, panel material grades, and specified load-bearing parameters. It should be explicitly noted that no physical prototypes were produced during this alternative selection stage. Therefore, the ratings of the technical criteria represent evaluators' concept-level perceptual assessments based on clearly defined design specifications rather than actual measured product performance.

The evaluation was conducted using a seven-point scale ranging from 1 to 7, on which evaluators rated the perceived performance of each alternative with respect to each criterion. The collected ratings were averaged to construct the initial decision matrix shown in Table 6, and the final evaluation results are reported in Table 7.

Table 6. Initial Decision Matrix of Modular Wardrobe Design Alternatives

Secondary Criterion	Information-based Weight (w_j)	Design Alternative 1	Design Alternative 2	Design Alternative 3
S11 Internal Functional Zoning	0.0933	6.4	6.0	6.9
S12 Corner-Space Utilization	0.1009	5.8	6.8	5.5
S13 Ease of Clothing Access and Retrieval	0.0896	5.9	5.6	6.8
S14 Storage of Special Items	0.0795	5.5	6.7	5.7
M11 Adjustability of Storage Accessories	0.0925	6.8	6.2	6.5
M12 Damage-Free Assembly and Disassembly	0.1053	6.7	6.5	6.4
P11 Structural Safety Mechanisms	0.0771	6.3	6.2	6.1
P12 Hardware Durability	0.0756	6.4	6.3	6.4
P13 Wardrobe Sealing Performance	0.0838	6.0	6.1	6.0
P14 Environmental Performance of Panel Materials	0.0647	6.6	6.5	6.5
E11 Aesthetic Appearance	0.0731	6.0	5.8	6.6
E12 Material Tactility	0.0646	6.1	6.0	6.7

Table 7. TOPSIS Comprehensive Evaluation and Ranking Results of Design Alternatives

Design Alternative	Euclidean Distance from the Positive Ideal Solution *D+*	Euclidean Distance from the Negative Ideal Solution *D-*	Relative Closeness Coefficient C_i	Ranking Result
Design Alternative 1	0.057	0.026	0.314	3
Design Alternative 2	0.052	0.051	0.495	2
Design Alternative 3	0.050	0.050	0.504	1

According to the final TOPSIS results, Alternative 3 obtained the highest relative closeness coefficient and was therefore identified as the optimal design alternative under the current evaluation conditions. Alternative 2 ranked second, while Alternative 1 ranked third.

To assess the sensitivity of the overall evaluation results to changes in criterion weights, 16 sensitivity analysis experiments were conducted. In Experiments 1 through 12, one criterion at a time was assigned a weight of 9, while all remaining criteria were assigned a weight of 1. In Experiments 13 through 16, the secondary criteria within one primary criterion category were simultaneously assigned a weight of 9, while all remaining criteria were assigned a weight of 1. The detailed experimental settings are presented in Table 8.

Table 8. Weighting Scenarios for the Sensitivity Analysis

Experiment	Weight Setting	Alternative			Rank
		1	2	3	
Experiment 1	w_{S11}=9, $w_{S12-E12}$=1	0.364	0.369	0.638	3>2>1
Experiment 2	w_{S12}=9, $w_{S11,\ S13-E12}$=1	0.262	0.684	0.310	2>3>1
Experiment 3	w_{S13}=9, $w_{S11-S12,\ S14-E12}$=1	0.275	0.317	0.691	3>2>1
Experiment 4	w_{S14}=9, $w_{S11-S13,\ M11-E12}$=1	0.184	0.672	0.365	2>3>1
Experiment 5	w_{M11}=9, $w_{S11-S14,\ M12-E12}$=1	0.471	0.420	0.514	3>1>2
Experiment 6	w_{M12}=9, $w_{S11-M11,\ P11-E12}$=1	0.369	0.479	0.492	3>2>1
Experiment 7	w_{P11}=9, $w_{S11-M12,\ P12-E12}$=1	0.341	0.486	0.504	3>2>1
Experiment 8	w_{P12}=9, $w_{S11-P11,\ P13-E12}$=1	0.315	0.483	0.519	3>2>1
Experiment 9	w_{P13}=9, $w_{S11-P12,\ P14-E12}$=1	0.304	0.489	0.513	3>2>1
Experiment 10	w_{P14}=9, $w_{S11-P13,\ E11-E12}$=1	0.315	0.483	0.513	3>2>1
Experiment 11	w_{E11}=9, $w_{S11-P14,\ E12}$=1	0.286	0.379	0.628	3>2>1
Experiment 12	w_{E12}=9, $w_{S11-E11}$=1	0.264	0.399	0.607	3>2>1
Experiment 13	$w_{S11-S14}$=9, $w_{M11-E12}$=1	0.245	0.541	0.478	2>3>1
Experiment 14	$w_{M11-M12}$=9, $w_{S11-S14,\ P11-E12}$=1	0.492	0.417	0.494	3>1>2
Experiment 15	$w_{P11-P14}$=9, $w_{S11-S14,\ M11-E12}$=1	0.352	0.484	0.501	3>2>1
Experiment 16	$w_{E11-E12}$=9, $w_{S11-P12}$=1	0.260	0.338	0.669	3>2>1

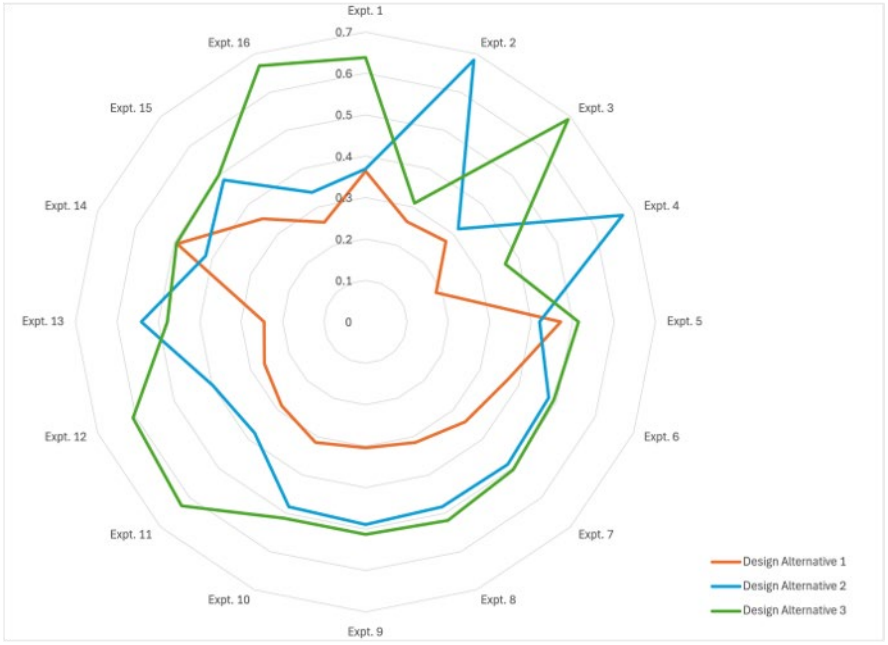


Fig. 9. Results of the sensitivity analysis

The sensitivity analysis results are shown in Fig. 9. Assigning a weight of 9 to S12 in Experiment 2, S14 in Experiment 4, and S11 through S14 in Experiment 13 amplified the advantage of Alternative 2, causing Alternative 3 to lose its top-ranked position. Nevertheless, Alternative 3 ranked first in 13 of the 16 experiments, suggesting that its ranking was reasonably robust to changes in criterion weights and that it remained the preferred alternative under most weighting scenarios.

Several limitations should be acknowledged. First, the sample size was relatively small. Second, satisfaction ratings were based on the wardrobes used by individual respondents. These wardrobes varied in price, dimensions, materials, period of use, and internal configuration, which may have affected the comparability of the ratings. Finally, no physical prototype was produced. Therefore, the ratings of the technical and material-related criteria reflect only perceived performance at the conceptual level rather than empirically validated product performance.

CONCLUSIONS

1. This study focused on modular wardrobes for compact living spaces. Through the importance-performance analysis (IPA) method, seven core evaluation criteria requiring urgent improvement and five criteria requiring maintenance of existing strengths were identified. The results indicate that spatial storage functionality, dynamic adaptability of modules, structural safety performance, and sensory aesthetic experience are the key factors influencing the user experience of modular wardrobes in compact spaces.
2. On the basis of the CRITIC information-based weight ranking, three modular wardrobe design alternatives with different design priorities were developed and comprehensively evaluated using the TOPSIS method. The results showed that, under the current evaluation conditions, Alternative 3 achieved the highest relative closeness coefficient, outperforming Alternatives 2 and 1, and was therefore ranked first. Alternative 3 demonstrated the strongest performance in fine-grained zoning and visually accessible storage. The sensitivity analysis further supported the relative robustness of its ranking across different weighting scenarios, suggesting that the alternative effectively addressed the target users' most pressing unmet needs.
3. This study proposed and validated a hybrid IPA-CRITIC-TOPSIS multi-criteria decision-making model, overcoming the limitations of traditional furniture design approaches that consider design criteria in isolation and rely excessively on experts' subjective judgments. Overall, the selected optimal alternative effectively addresses the core pain points of users living in compact spaces in terms of daily storage and relocation-based reconfiguration. This evaluation framework provides a more comprehensive and rigorous scientific assessment paradigm for the future development of sustainable customized furniture.

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To ensure transparency, the authors declare that ChatGPT (OpenAI) was used only for English translation and language polishing. All research design, data analysis, and conclusions were independently completed by the authors.

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APPENDIX A

Semi-Structured Interview Outline

No.	Question
1	Please describe your current living environment and your daily experience with clothing storage and management.
2	When purchasing or using a wardrobe, which performance aspects do you usually prioritize?
3	How do you evaluate the rationality of the internal functional zoning and capacity proportions of your current wardrobe?
4	How do you perceive the use of the top, bottom, and corner areas of the wardrobe? How do you usually handle these areas?
5	How important is unobstructed access to clothing in the core storage area when searching for clothes in daily use?
6	For special-sized items, such as extra-long skirts, large suitcases, or thick seasonal bedding, what kind of storage support would you expect a modular wardrobe to provide?
7	In which usage scenarios would the free adjustability of internal storage accessories be useful?
8	How would you evaluate the ability of a modular wardrobe to resist structural deformation under long-term load-bearing conditions or repeated assembly and disassembly?
9	What structural safety protection mechanisms do you think a wardrobe should have? Please explain your reasons.
10	How important are the smooth operation and noise performance of core mechanical components, such as drawer slides and cabinet door hinges? How do these components affect your user experience?
11	In the event of future relocation or room function adjustment, what are your expectations regarding the ease of initial wardrobe assembly and the ability to disassemble and reconfigure it without damage?
12	Does convenient independent part replacement and later capacity expansion affect your long-term use of the wardrobe?
13	Do you consider the environmental performance, non-toxicity, and health safety of wardrobe panel materials to be important factors?
14	How do wardrobe sealing performance and moisture-proof and mildew-proof properties affect your user experience?
15	How important is the stylistic coordination between the wardrobe appearance and the overall bedroom environment?
16	What kind of visual and tactile surface qualities do you prefer, such as fingerprint resistance and scratch resistance? Do the choices of color and form influence your sense of psychological comfort?
17	How practical do you consider internally integrated smart assistance and lighting modules to be? Which type of assistance do you prefer?
18	What expectations do you have for low-maintenance cleaning of the wardrobe interior and bottom space in daily use?
19	In addition to the above topics, do you have any other opinions, requirements, or suggestions regarding modular wardrobe design?